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RECONFIGURABLE G & C COMPUTER STUDY FOR SPACE STATION USE

FINAL REPORT

VOLUME V

APPENDIX 3

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ILLUSTRATIONS

TABLES

1.0 SYSTEM ANALYSIS AND TRADE-OFF STUDIES

1.1 INTRODUCTION

This appendix contains a detailed report of system analysis studies of the G&C Space Station system. The objective of the system analysis is two-fold:

    (1) To determine the computer requirements

    (2) To perform a performance error analysis of the G&C system

In addition, this appendix contains the results of trade-off studies conducted to determine the distribution and hierarchy of computations in the G&C system.

Section 2.0 contains the system analysis to define the computer requirements and the trade-offs on the distribution and hierarchy of computations. Section 3.0 contains the performance error analysis. The detailed derivation of the equations that led to the computer requirements of Section 2.0 are contained in the Sixth Monthly Progress Report.

2.0 COMPUTER REQUIREMENTS DERIVATION AND TRADE-OFF STUDIES

The objectives were to establish the computational requirements of the G&C system with respect to mission phases and to identify the various computational requirements in detail for the Strapdown Inertial Unit (SIRU), the Optical Attitude Sensors (OAS), the Control Moment Gyros (CMGs), and the Reaction Control System (RCS) together with gross estimates for the Rendezvous subsystem, the Docking subsystem, and the Balance Control subsystem.

The computational allocation trade-offs conducted included only those for subsystems designated for the detail analysis, namely, the SIRU, OAS, CMGs, and RCS.

2.1 SYSTEM ANALYSIS

In view of having little or no requirements for the prelaunch checkout phase and for the boost phase of the mission, most of the effort was concentrated on the manned orbital phase of the mission. The unmanned orbital phase of the mission was considered a subset of the requirements for the manned phase, and therefore was estimated as being an integral part of the Executive program only.

In performing the systems analysis for the manned orbital phase, two cases were selected. In the first case, all computational requirements were designated as being performed in the central computer. This case is defined as having minimum preprocessors. The second case assumes processors located at the subsystem level and that all of the computations associated with the subsystem of interest could be performed within its processor. This case is defined as maximum preprocessing. The latter case, however, is only applicable to the four subsystems subjected to the detailed analysis.

The results of the analysis is given in Table 2-1 and corresponds with the requirements for the G&C central computer only. For purpose of sensitivity with respect to evaluating the four subsystems studied in detail, two sets of values are given in the table. The set designated by the letter "a" includes the requirement for all of the subsystems and furthermore, includes the various housekeeping functions necessary for program control of the central computer. The second set of values designated by the letter "b" indicate only that part of set "a" dealing with the four subsystems for which maximum preprocessing was estimated. That is, set "b" represents only the SIRU, OAS, CMGs, and RCS.

In viewing Table 2-1, the most significant change between maximum and minimum is in the speed requirement and data rates. However, if the central computer is configured to have four computers operating in parallel, the memory also becomes significant. That is, the difference between maximum and minimum would be approximately 40,000 words. For this reason, and for the fact that on-board checkout and backup functions were not mechanized at this time, a certain amount of preprocessing is recommended at this level of the total system analysis.

Table 2-1.   Computational Requirements Comparison Table for
Central Computer Complex

Central Computer Computational Requirements	Preprocessing Configurations		
	Minimum	Maximum	Recommended
Memory Storage (words)			
a.	38,600	28,300	29,600
b.	17,400	7,100	8,400
*Speed (operations/sec)			
a.	994,000	410,000	500,000
b.	805,000	264,000	350,000
Data Rates (words/sec)			
a.	21,300	4,600	5,500
b.	20,800	4,300	5,000
**Maximum Word Size			
a.	24	24	24
b.	24	24	24

*Number given implies short operations (add, subtract, etc.) with long operations (Mult, Div., etc.) equivalent to 2 short operations.

**Nominal word size equals 16 bits/word

NOTE: The letter "a" implies total G&C computational require-
ments for the full subsystem configuration. The letter
"b" implies the G&C computational requirements dealing
with only the SIRU, OAS, CMGs, and RCS in which pre-
processing was explored.

The recommended configuration assumes the SIRU, CMGs, and RCS to have dedicated local processors. The OAS, while requiring a memory capacity on the order of the three other systems, requires such an insignificant duty cycle (operations/sec) that use of preprocessing is not justified at this point in the analysis. If the requirement for using the data derived from the OAS were significantly increased or from a commonality trade-off, then the use of local processing may be reasonable.

The amount of preprocessing recommended for four subsystems analyzed is discussed in the following paragraph.

2.2 TRADE-OFF STUDIES

Trade-off studies were conducted for the four subsystems mentioned to determine the best allocation for performing the various computations required of each subsystem to carry out the mission requirements. To accommodate this, the computational requirements involved with each of the subsystems were divided into separate program modules which would be sequentially executed in time. Each program module and sequentially executed combinations of modules were evaluated as being processed at the subsystem level with the remaining modules being executed in the central computer.

The program modules designated for trade-off for the four subsystems are defined as follows:

SIRU

I-1. Filter Instrument Outputs (gyros and accelerometers)

I-2. Failure Detection and Transformation to Body Coordinates (gyros and accelerometers)

I-3. Direction Cosine Matrix Update

I-4. Direction Cosine Orthogonalization

I-5. Generation of Attitude Error Signals

OAS

P-1. Failure Detection

P-2. Compute Horizon Sensor Scanning Angles

P-3. Process Measured Data

P-4. Compute Horizon Sensor Pointing Angles and Rates

P-5. Compute Star Tracker Pointing Angles and Rates

P-6. Make Star Selection

CMGs

I.   Control Mode Detection

II.   Torque Error Computation

III. Momentum Error Computation

IV.   Desaturation

V.   Failure Detection and Isolation

VI.   Reconfiguration

RCS

I. Control Mode Detection

II. Torque/Force Computation

III. Engine Value Control

IV. Failure Detection

V. Failure Isolation .

VI. Reconfiguration

The computational requirements with respect to the program modules listed are presented in Table 2-2. The memory storage symbols ROM and RWM indicate read-only memory and read-write memory respectively. A design allowance of 40 percent for memory and 30 percent for speed is provided in the table for purpose of overall sizing. The memory allowance, however, is considered low in that the estimates were obtained directly from the mechanized equations with no "pad." Additionally, an executive, diagnostics, I/O storage and control and utility package were not included in the estimate for the mechanization. Possibly a fifty to sixty percent allowance would be more reasonable.

The recommended computational allocation configuration is given in Table 2-3. Included in this table along with memory and speed are the number of data signals transferred between the subsystems and the central computer and the maximum expected word length. The number of data signals indicated, especially in the case of the RCS, include failure and reconfiguration flags (discretes) for on-board recording as required. The subtotals given in the table would assume all of the modules as being computed at the subsystem level, this is not the case, however. The recommended allocation configuration does not include I-5 in the case of the SIRU, none of the OAS modules, and modules I and II of the CMGs and RCS as being performed in the local processor. Furthermore, the recommended system assumes that a local processor is associated (physically located) with each engine station which in this case reduces the load at each station. However, the effect on the central computer is an increase over having the single local processor configuration complex.

In viewing the estimated requirements imposed on the local processors, the application of the standard processor submitted by MSC, NASA is not applicable for use with the SIRU or the CMGs. If the update rates were to be relaxed for the SIRU by a factor of at least 5, the standard NASA processor could be based on these estimates. In the case of the CMGs, it appears that the RWM would be very marginal and therefore not recommended for use with the CMGs.

Table 2-2. Subsystem Program Module Requirements

Subsystems and Program Modules	Memory Storage		Speed (ops/sec)
	ROM (words)	RWM (words)	
SIRU:			
I-1	400	50	26,500
I-2	1,100	150	184,000
I-3	100	10	62,000
I-4	200	20	Background
I-5	400	20	84,000
Subtotal	2,200	250	356,500
Design Allowance	800	100	110,000
Total	3,000	350	466,500
OAS:			
P-1	50	10	Background
P-2	150	20	Background
P-3	250	100	Background
P-4	600	60	Background
P-5	200	20	Background
P-6	300	20	Background
Subtotal	1,550	230	---
Design Allowance	650	70	---
Total	2,200	300	---
CMGs:			
I	10	---	200
II	150	30	1,600
III	200	50	15,400
IV	250	50	15,000
V	800	200	18,000
VI	700	100	(See Note 6)
Subtotal	2,110	430	48,200
Design Allowance	990	170	15,000
Total	3,110	600	63,200

Table 2-2. (continued)

Subsystems and Program Modules	Memory Storage		Speed (ops/sec)
	ROM (words)	RWO (words)	
RCS:			
I	20	--	1,000
II	250	50	15,200
III	150	50	30,000
IV	500	100	89,000
V	1,700	360	18,200
VI	1,200	200	(See Note 6)
Subtotal	3,820	760	150,200
Design Allowance	1,520	220	45,000
Total	5,340	980	195,000

NOTES:

1. I-5 not included in recommended configuration.

2. OAS not included in recommended configuration.

3. Design Allowance is considered minimum.

4. Operations/second assumes long ops = 2 short ops.

5. Background implies duty cycle of less than 1 sec and in this case requires less than 500 ops/sec/module.

6. Reconfiguration is not considered as part of normal duty cycle.

7. The estimate for the RCS is given here as if a single local processor complex would service all four engine stations.

8. Modules I and II for both CMGs and RCS are not included in the recommended configuration.

Table 2-3. Recommended Computational Allocation Configuration

Subsystem and Program Modules	Memory Storage		Speed (ops/sec)	Interface Data Signals	Maximum Word Length
	ROM (words)	RWM (words)			
SIRU:					
I-1, 2, 3 and 4	2,520	330	382,500	20	24 bits
OAS:					
None	--	--	--	16	16
CMGs:					
III, IV, V and VI	2,950	570	61,400	77	16
RCS:					
III, IV, V and VI	5,070	930	179,000	242	16
RCS:*					
III, IV, V and VI	2,100	450	72,000	152	16
*Recommended Configuration (processor located at each station)					

The recommendations given in this report are the results of a limited analysis and should be considered in this light. For example, on-board checkout was not considered in any depth nor were any detailed requirements analyses performed on any of the other subsystems, other than those mentioned. Even in the case of the subsystems for which detailed analyses were performed, the candidate system studied may have already changed thereby changing many of the requirements estimated herein.

For further trade-off evaluation, refer to Section 2.9 of this report.

2.3 SYSTEM APPROACH

2.3.1 General Approach

The study approach has been based upon the contract statement of work with modifying assumptions or directions received from NASA, MSC and with applicable mission and system requirements obtained from NR - Space Division.

The contract study concerns the G&C system for the Space Station with emphasis on the reconfigurable digital computer. However, a NASA technical request to consider or include Logistics Vehicle G&C system requirements resulted in its general inclusion. As a consequence, certain subsystem data rate processing was increased as well as some signals being processed additionally. The principal considered objective in including Logistics Vehicle requirements is to arrive at a commonality solution in equipment and computer routines.

The G&C system, as defined by the Work Statement, includes four principal subsystems which require investigation into their preprocessing functions and their respective input/output interfaces. These four principal subsystems are defined as the Strapped-Down Inertial Reference Unit (SIRU); Optical Attitude Sensors (OAS); Control Moment Gyros (CMGs); and Reaction Control System (RCS). In addition, the G&C computer is to receive signals and perform computations associated with three other subsystems. These three subsystems are defined as Rendezvous (calculations and commands to incoming Logistics or other vehicles); Docking (calculations and commands); and Balance Control (computations and commands for the Space Station during spin for its artificial "g" mode). An eighth subsystem, primary propulsion, was documented by mutual agreement to be deleted since it was determined early in the study that this subsystem would not exist on the Space Station. Instead, the function of this subsystem would be replaced by the G&C computer determining orbital makeup commands from its navigation computations with the propulsive thrust being applied by the RCS in translation.

Pursuant to determining system requirements and computer reconfiguration, computations associated with the seven subsystems were determined. In addition, requirements for the four primary subsystems in status monitoring, fault isolation, and signal interface were determined. The total computational requirements for the four subsystems were apportioned according to the extent of subsystem preprocessing with the remainder of the computations being assigned to the reconfigurable digital computer. This apportionment corresponded to tradeoff determinations in computational assignment, amount of required equipment in the sense of different extents of required redundancy, input/output interface, and data bus requirements. The preprocessor apportionments corresponded to maximum preprocessing, minimum preprocessing, and selected degrees of intermediate preprocessing.

Operational requirements for the reconfigurable digital computer, as defined in the Work Statement, are that the computer shall be Fail Operational, Fail Operational, Fail Safe. This requirement has been interpreted to require four G&C computers. Early program communication with NASA, Houston, resulted in the same stipulation to the data bus - four data buses are to be used.

No particular failure philosophy has been assigned to the total G&C system for purposes of this study. The Fail Op, Fail Op, Fail Safe assignment to the digital computer may be interpreted to insure that the digital computer and its

transmission system shall not be a weak operational link in the G&C system. In one instance, the G&C system requirement has been stated to be Fail Op, Fail Safe for the Space Station since no real critical functions are considered to exist. However, a greater Fail Op criteria, to at least Fail Op, Fail Op, Fail Safe, is used in the system approach since appreciable subsystem redundancy is inherent (as well as considerations for the Logistics Vehicle). For example, for at least a significant portion of mission time, the SIRU and OAS in the sensor subsystems and the CMGs and RCS in the torquer subsystems are mutually redundant. In addition, other provisions, not included in this study, increase the operational aspects of Space Station G&C operation. These provisions will consist of manual orientation and control as well as probable manual navigation. With regard to each of the four primary subsystems, each subsystem individually will have dual redundancy as a minimum. This duality will include associated subsystem and interface electronics as well as preprocessors.

This approach of duality, as a minimum, on the subsystems and the requirement for four digital computers indicates a significant factor with regard to trade-off determinations as to whether certain computations are to be performed in the subsystem preprocessors or in the digital computer.

2.3.2 Subsystem Assumptions and Definitions

2.3.2.1 SIRU — As per Exhibit C of the Work Statement, the strapdown concept of six single degree of freedom gyroscopes and six linear accelerometers in a dodecahedron array are to be used for inertial reference. These instruments are of the pulse-rebalance type. An update rate of 100 times/sec is to be used. The SIRU is a MIT concept under development. Contract instructions were to use the MIT description for this subsystem. The concept includes digital computations for failure detection and isolation. The failure operational aspects are that Fail Op is obtained with two gyros (or accelerometers) failed and isolated. Continued system operation occurs with up to three gyro failures. However, the third failure cannot be isolated. Thus, the mechanical (gyro) redundancy would appear to be four; i.e., a fourth failure could occur for Fail Safe operation. The referenced concept uses dual electronic redundancy which includes power supply, interface processing, and data transmission. The application of a higher level of electronic redundancy is a trade-off consideration for this contract study.

Application — The SIRU is not to be operated during the period of Space Station spin for artificial "g" (nor is navigation to be performed). From the Space Station standpoint of operation, the use of the SIRU accelerometers and their signal processing is not warranted. In addition, the quiescent dynamic conditions would permit the update rate to be reduced to at least 10 times/sec. However, the concept and assumptions as used are applicable to the Logistics Vehicle.

2.3.2.2 OAS – The OAS includes both star trackers and horizon scanners. As per Exhibit D of the Work Statement, the sensors are assumed to have dual redundancy and the sensor error signals will be available in both analog and digital form. Each two gimbaled star tracker is assumed to contain two heads so that three axes of attitude information are available. Each two gimbaled horizon scanner has two heads to obtain two-axis of attitude information. The initial interpretation of the Work Statement, as well as past space application usage, assumed that the horizon scanner error signal outputs corresponded directly to the local vertical angles (two-axes). However, this assumption was changed during the course of the contract, as a result of communications with NASA, Houston, to use a horizon scanner concept under development. This development effort is to improve navigational accuracy by detecting the 50 km CO_2 altitude at the horizon. As a result, local vertical must be computed. Additional computations are required in interpreting the sensor array element outputs on a comparative basis to determine the 50 km altitude. Since the OAS processing in this approach uses the output signals for long term navigation and long term SIRU drift calibration with appropriate filtering/smoothing, the update rate can be quite low. An update rate of once/1,000 sec is used in this approach. Status monitoring and failure isolation is required.

Application – From a subsystems operation impact on the total automatic G&C system operation, there is only an incidental difference whether the star tracker has two heads or has a single head for time sharing. Certainly the assumed update rate will permit time sharing. The principal difference would be in the extent or degree of gimbal freedom in one axis and the need for successive acquisition of target stars. From a backup standpoint, particularly under manual control, the two-head arrangement would be preferred for purposes of inertial hold attitude control. Since it is expected that approximately 97 percent of the mission time (with the exception of the nominal one month duration of artificial "g") will be in the local vertical mode of control, a conventional horizon scanner having local vertical error outputs is likely to be preferred from a manned operational standpoint. Although the use of a sun sensor is not a part of this contract effort, a sun sensor is likely to be used for at least coarse alignment. Application of the OAS for the Space Station and for the Logistics Vehicle during nonthrusting exoatmospheric mission intervals are generally equivalent.

2.3.2.3 CMG – As per Exhibit E of the Work Statement, the CMG system will use three double-gimbal CMGs. The system is to be used for cyclic control events in attitude hold and for low rate maneuvers up to 0.002 deg/sec. The H-vector control law is assumed. An update rate of 20 times/sec is assumed per Work Statement. Desaturation of the CMGs will use the RCS. A guideline of using 30 variables for status monitoring is given in the Work Statement. It is assumed that the three CMGs are configured for zero net angular momentum at gimbal nulls for purposes of accommodating mission modes of local vertical hold and artificial "g."

Application – The use of CMGs is applicable for trade-off only to orbital missions of extended durations. CMGs have no application for the Logistics Vehicle.

2.3.2.4 RCS – As per Exhibit F of the Work Statement, the RCS includes four stations of four jets each. The sixteen jets are arranged to produce pure couples about the three control axes under normal operation. The RCS is used to remove high rate transients; provide higher attitude maneuver rates up to 0.05 deg/sec; desaturate the CMGs and provide translation for orbital makeup/stationkeeping. A dual bi-propellant source is available to each RCS station and the distribution is locally controlled by quad valves in each propellant line. Each jet is assumed to be controlled by quad valves (series-parallel) in each of the fuel and oxidizer lines. The jet valves are assumed to be normally closed. The RCS station source distribution valves and the main source supply quad valves are assumed to be normally open. (In addition, isolation valves for manual control will likely be used.) Status monitoring of 84 analog signals from assorted pressure, temperature, and flow rate sensors is to be implemented according to the MIT concept for the Logistics Vehicle. This concept indicated a desire to control each jet valve individually. However, a count of the concept command signals permits only two commands per jet. This apportionment is assumed to be one per propellant line. However, a change could be made to have one command correspond to a series path (two valves) of both a fuel and oxidizer line. Individual jet valve isolation may be accomplished by power distribution control if required.

The required update rate of the RCS depends on several factors. Among them are the angular acceleration level imparted, the desired increment of delivered angular rate, and the allocation of computation (digital computer or preprocessor) as well as the type of computational compensation. An update rate of 50 times per second was initially used in the study. However, subsequent instructions from NASA, Houston, were to use an update rate of 200 times per second if computations are performed in the digital computer with 50 times per second being permissible if computations are performed at the subsystem level and a local clocking controller is present. The update rate of 200 times per second was therefore assumed for all cases for trade-off purposes. The instructions also included processing two (2) status monitoring parameters per jet at the 200/sec rate with the remaining parameters to be monitored at a rate of ten (10) times/sec.

Application – With the considered noncriticality of the RCS for the Space Station (among other factors, twelve or more valve failures can occur for Fail Safe operation) and the intended use of the RCS, an update rate much less than specified would be adequate. However, if the RCS is to assume the total role of attitude control in the event of complete CMG failure, an update rate of 20/sec could be considered adequate. In addition, it would seem that the status monitoring approach (as well as the degree of valve redundancy) can be greatly simplified for the Space Station. The approach used corresponds to the MIT concept intended for and is considered more applicable to the Logistics Vehicle.

2.3.2.5 Rendezvous – The G&C digital computer is to perform backup rendezvous computations for the Logistics Vehicle. This function is readily transferable to performing rendezvous guidance for orbital shuttles which position detached experiment modules. Sensor signals relating to range and two LOS (Line-of-Sight) angles are assumed available on the data bus and the rendezvous commands are issued to the data bus for subsequent transmission. Thus, no interfacing equipment requirements are required as a part of this effort. Two approaches are used in sizing the computer requirements for this particular subsystem. The first method used is a representative set of rendezvous equations considered to be simple equations generally equivalent to cross-product steering. The second approach, which is used for the estimation numbers, entails surveying the equations used in the Apollo/LEM rendezvous. This approach is much more sophisticated and complex. The estimated values for this approach are derived from combining programming estimates from two separate and independent Apollo simulations with a gross extrapolation of the Apollo rendezvous equations. Because of the nature of this study, the estimates from the latter approach are used for the estimates given herein.

Application – The rendezvous equations are applicable for computation and command by the Space Station or for the terminal rendezvous phase on-board computations by the Logistics Vehicle. However, the latter may use a more sophisticated set of equations in practice.

2.3.2.6 Docking – The G&C digital computer is to perform docking computations with the interface being the data bus (as for rendezvous). It is assumed that the docking commands consist of six (6) DOF (degree-of-freedom) commands of three axes translation and three axes attitude control. Past docking operations have been manual and no references were available for automatic docking. Therefore, computations were assumed for a configuration wherein the Space Station docking sensor(s) would measure range and two (2) LOS angles to each of three (3) reflectors (or transpondors) located on the incoming vehicle (logistics vehicle or orbital shuttle). The computations would use the sensed parameters to determine the positional error and the three axes of attitude from which the six (6) DOF commands are computed and issued to the data bus. The docking sensor(s) are assumed offset from the docking port in a longitudinal direction.

Application – The computations are generally applicable for solution by either the Space Station G&C computer or the Logistics Vehicle G&C computer. However, the Logistics Vehicle would probably employ its short-term inertial reference with the docking sensors in providing attitude measurements and corrections. In addition, a sensor-to-docking port offset would not necessarily be required for Logistic Vehicle performance of docking computations.

2.3.2.7 Balance Control – The G&C digital computer is to perform computations for balance control. This subsystem definition is limited to the Work Statement: "The balance system will compensate for large shifts of mass on the Space Station

such as shuttle craft docking and undocking or elevator and cargo motion. This system will only be used during artificial "g" phases. The G&C computations are to be based upon data available from and to be delivered to the data bus. Computer estimates for this subsystem are based entirely on assumptions since no references are available. The available sensor information assumes simple sensors since it is assumed elsewhere that the SIRU and the OAS (no navigation) will not be operating during spin. However, it is assumed that the normal attitude control computer routines may be employed in addition to second order equations to account for the additional dynamics of spin. It is assumed that the balance control commands may take the usual form of CMG or RCS commands; although the CMG gimbals may be locked for passive wobble damping. The Work Statement indicates the desire to control the spin axis during artificial "g" periods through precession using the RCS. Although subsequent mission analysis may indicate that the station may be allowed to precess due to the required energy expenditure, estimates are made to provide precession control by the RCS. It is assumed that the pitch jets are synchronized for firing about a median angle in yaw (0° and 180°) to most efficiently control precession.

Although no interpretations were available from the Work Statement, computational estimates were made for Static Balance (the previous assumptions relate to Dynamic Balance). The data available for Static Balance would generally be associated with housekeeping assignments. However, the inclusion of Static Balance to G&C computer assignments may be based on minimizing Dynamic Balance requirements as well as enhancing zero "g" operation to account for gross changes in moments-of-inertia and moment arms resulting from the absence or presence of large masses such as the Logistics Vehicle.

Three compartmentized bodies were assumed for the Space Station proper with each body being subdivided into as many as eighty (80) volume mass distributions. In addition, up to six attached bodies were assumed. With the data entry of the appropriate body partitioning (up to 246 entries) in terms of mass coordinates, the computer determines the overall mass center. The mass centroid (unbalance) is used as a display or command output under the assumption that the mass unbalance is to be shifted prior to spin up unless the "g" forces are to be used to effect some mass shifts.

Application - Balance control is applicable only to the Space Station for the intended purposes. However, the principle of static balance computations may be used for loading stores aboard the Logistics Vehicle.

2.3.2.8 Data Bus Interface - The previous interpretation of four computers and four data buses is assumed as a system requirement so that a weak operational link does not result from this portion of the system. However, it does not necessarily assume that each subsystem must be serviced by four data buses. The number of data buses which service each subsystem (whether two as a minimum, three, or four) is subject to trade-off determinations on its own failure criteria mertis. In a similar manner, the extent of required interface electronics redundancy, whether interface/data bus voting is required, or whether redundant elements/buses are standby or shutdown are subject to trade-off.

2.3.3 <u>System Study Approach</u>

The G&C system approach is depicted in Figure 2-1 in the form of a study flow diagram for Tasks 3 and 6. The output of these tasks are shown to be inputs for Tasks 7 through 11. The error analysis portion of Task 3 is considered as an independent effort and is reported in Section 3 of this Appendix.

After the subsystem assumptions and ground rules were obtained (as discussed in 2.3.1 and 2.3.2), the mechanization for the G&C system was determined according to individual subsystems and the total system. The primary effort pertained to the study flow through the computational determinations activity. However, a gross subsystem redundancy level was determined for the four primary subsystems as an aid to performing Task 9.

The computational requirements were determined by mission phases/modes. Computational requirements and data bus requirements were determined for the three subsystems of Rendezvous, Docking, and Balance Control. These computational requirements were assigned to the G&C computer for use in Tasks 7 and 8 since their interface responsibility was not a part of this contract effort. The computational requirements for the four primary G&C subsystems (SIRU, OAS, CMGs, RCS) as well as the monitoring, isolation, interface signal processing, and the data bus signals were determined. These determinations were tabulated according to software modules so that computational blocks could be readily assigned to a subsystem preprocessor or to the G&C computer. Tabulations were made to enhance Task 6 trade-offs according to maximum preprocessing and to minimum preprocessing wherein a maximum of required computations were assigned to the G&C computer. Data bus signal lists were made for each level of preprocessing.

Task 6 studies consisted of initially allocating different combinations of computational blocks to either the G&C computer or to the subsystem preprocessors. The level of allocation corresponded to subsystem maximum, minimum, and intermediate preprocessing. Included with the trade studies in computational allocations, processing of monitoring and isolation signals as well as data bus signals were tabulated corresponding to the level of preprocessing. The allocation of requirements to preprocessors had negligible effect with regard to considered redundancy of preprocessors since three of the four subsystems are to be located in a single vehicle position. However, the approach to preprocessor redundancy for the RCS, in which a single location for preprocessors up to a maximum of four locations was considered, results in a difference in the number of monitoring and isolation signals required.

The suitability of a standard LP (Local Processor), whether NASA developed or otherwise, to perform the trade-off levels of preprocessing was investigated. The pacing factors were memory storage and operational speed with word length and data bus activity as secondary factors.
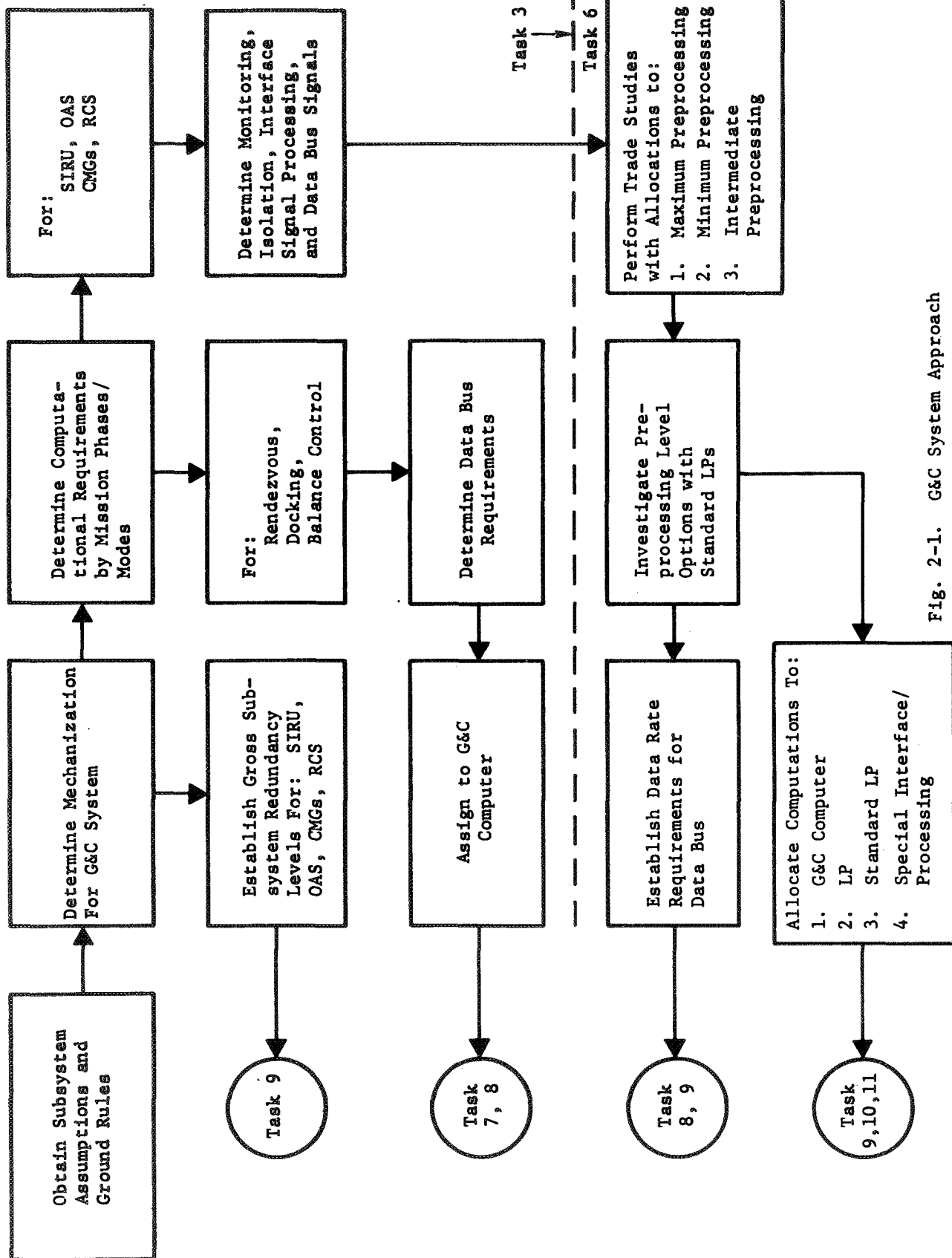
Fig. 2-1. G&C System Approach

Data rate requirements for the data bus were determined as a result of the trade studies. These requirements serve as inputs to Tasks 8 and 9.

The trade studies also resulted in allocating the computations associated with the four subsystems to the G&C computer, the NASA standard LP, other standard LPs and/or special interface or processing equipment. This allocation was determined as an input to Tasks 9, 10 and 11.

Other G&C system related activities such as power distribution and man-machine or other computer interface with the G&C computer were not included in Tasks 3 and 6 system studies since they are separate study entities in themselves.

2.3.4 Subsystem Gross Redundancy

The G&C system may be interpreted in a gross redundancy sense at the subsystem level. Using the subsystem assumptions and definitions of Section 2.3.2, a baseline G&C System Operational Redundancy Flow Diagram is shown in Figure 2-2. The numerals inside each box in the figure indicate the level of redundancy and the letters M, E, and T indicate mechanical, electrical, and transmission (data bus) redundancy, respectively. Electrical redundancy considers the lower level of preprocessors or other electrical signal processing circuitry. Mechanical redundancy is directly associated with the subsystem assumptions and definitions. Fail-Safe is considered to correspond to the level of redundancy, assuming that power-off circuitry insures against hard failures. The Fail-Op level is considered to be one level less than the redundancy level.

As previously discussed, the full certainty requirement of computer failure knowledge in conjunction with Fail-Op, Fail-Op, Fail-Safe operation has received a ground rule interpretation of requiring four G&C digital computers and four interfacing data buses. However, the failure criteria has not been established for the subsystems. The absence of this criteria indicates that the data buses (T) servicing each subsystem need not be redundant to a level of four. Considering the fact of the mechanical integrity of the transmission wire, it would seem that the transmission redundancy to each subsystem need be no higher than the lowest level of redundancy associated with each subsystem. This is an important consideration since it impacts any considered need for data bus voting and the operating status (off, on-standby, on-operating without outputs, or on-operating) of the redundant preprocessors associated with each subsystem as well as voting on the computer terminal end of the data bus.

The level of redundancy shown in Figure 2-2 would indicate the sufficiency of dual transmission redundancy with the exception of possible higher redundancy for the RCS. Absolute transmission redundancy may be increased using dual transmission redundancy to each subsystem by virtue of the mutual functional redundancy of the SIRU with the OAS and the CMGs with the RCS. As an example, if the SIRU and CMGs are serviced by Data Buses 1 and 3 and the OAS and RCS are serviced by Data Buses 2 and 4, then control system operational capability may realize a four-level transmission redundancy (with appropriate software back-up capability) while requiring only dual transmission redundancy to each G&C subsystem.
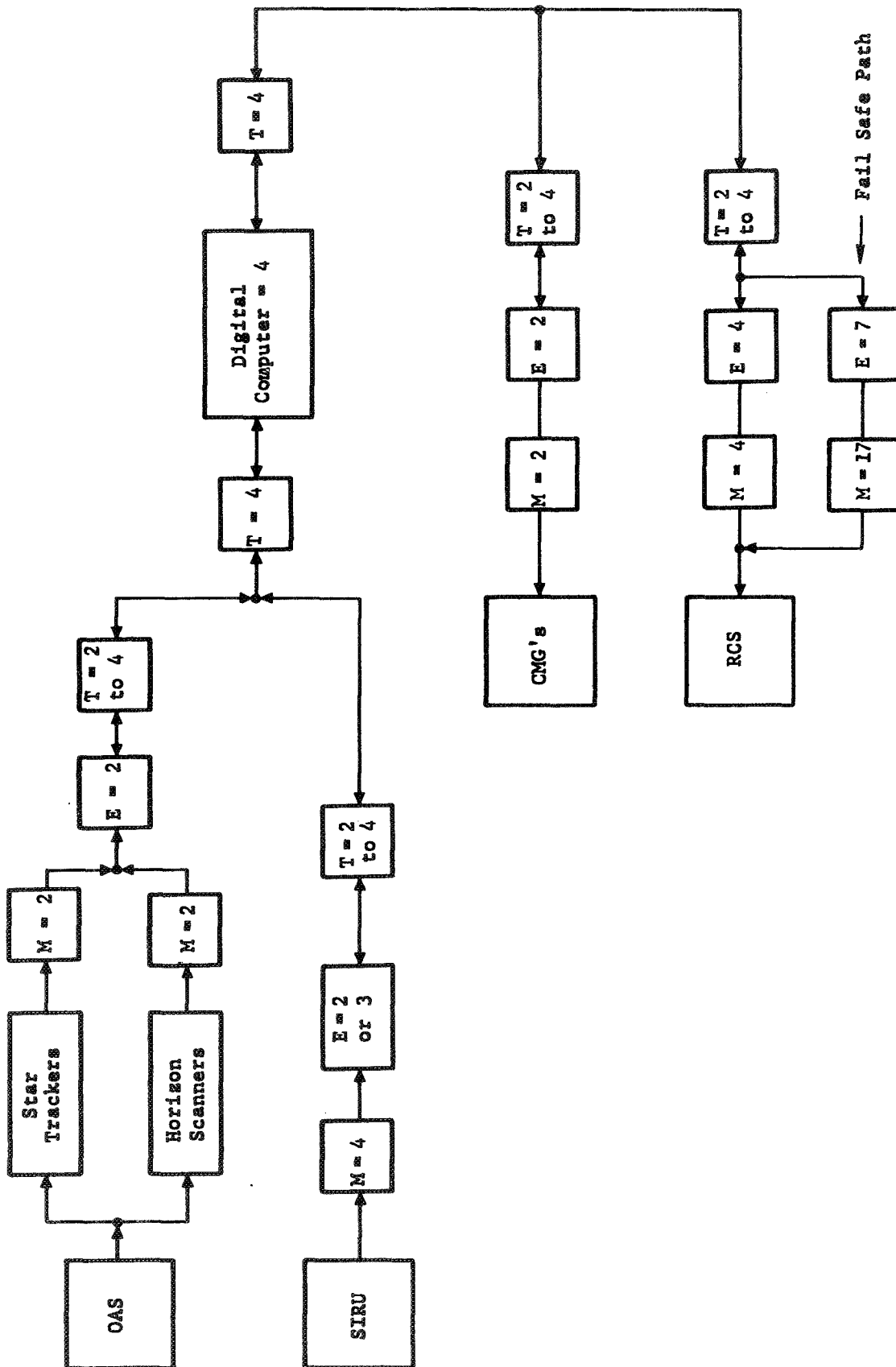
Fig. 2-2. Baseline G&C System Operational Redundancy Flow Diagram

The mechanical redundancy of the OAS is interpreted as dual by virtue of the dual star trackers and dual horizon scanners in which a failure in one of the two gimbals on one of the instruments fails that instrument and a single gimbal failure in the dual instrument fails the dual instrument. Instrument optics failure may be considered on the same level as the mechanical gimbal failure. Since the OAS mechanical redundancy is limited to dual, dual preprocessors should be adequate with a single preprocessor capable of accommodating both the star trackers and the horizon scanners.

The mechanical redundancy of the SIRU is defined as four level in the MIT report since it is stated that continued system operation is available with three gyro failures; however, the third failure cannot be isolated. The report suggests dual redundancy on the power supply and preprocessor as a result of higher reliability. Thus, dual electronics redundancy may be considered adequate on a reliability basis. However, on a failure criteria basis, triplicate preprocessors may be considered in order to take advantage of the higher level of mechanical redundancy. Dual preprocessors may be preferred if all of the other subsystem preprocessors are dual in order to have a common failure interpretation and switch-over routine.

The CMGs are interpreted to have dual mechanical redundancy. This limitation is principally based on the gyro spin bearings (as well as the spin motor circuit if it is not redundant to each gyro). In addition, this limitation is expected to apply to the precession torquing gimbals in one control axis. Therefore, with the expected higher electronic reliability, it is assumed that dual preprocessors are adequate for the CMGs. In a similar manner, dual transmission should be adequate, although transmission redundancy as high as four is indicated as a possibility in Figure 2-2.

With regard to the RCS, it is assumed that the dual bipropellant source quad valves are under at least dual redundant electronic control apart from the control of the four RCS stations. Although manual isolation valves and check valves may be present in the propellant distribution system to enhance the operational criteria, the presence of these valves will not be included in a redundancy assessment. Due to the impingement of the hypergolic bipropellants constituting certain combustion and the mechanical integrity of the thrust chamber assembly and nozzle, mechanical failure criteria is associated with the propellant distribution and control valves. Of course, a casualty which physically destroys a jet would be in a different failure category which the RCS subsystem would fulfill.

Each RCS station has station distribution valves (subsequently referred to as reactant valves) which are quad valves placed in each of the propellant lines after the dual source propellant lines have been manifolded. A set of station distribution valves supplies four jets at each RCS station with each propellant line to each jet being controlled by quad jet valves. The jet valves operate normally closed wherein applied power is required to keep them open. The station distribution valves as well as the source valves are assumed to operate normally open.

The RCS redundancy path in Figure 2-2 shows two paths. The top path corresponds to the redundancy toward Fail Op and the lower path corresponds to redundancy for Fail Safe. The limitation of mechanical redundancy toward Fail Op is four by virtue of the possibility of a single valve in each companion (couple for torque) jet parallel feed path failing closed. This limitation applies to only one of the propellant lines, i.e., all four closed, parallel feed, companion jet valves must be in the fuel line or all four must be in the oxidizer line. Hence, Fail Op is provided if three worst condition valves fail closed. The limitation of mechanical redundancy toward Fail Safe is interpreted to be 17. This number is arrived at by the following: All twelve valves in any series combination path supplying both sources of one propellant (say fuel) to both companion jets (two jet valves plus two distribution valves, plus two source valves times two for the number of stations and sources) may fail open. Also, five of any series combination of valves in either of the oxidizer lines to either of the two companion jets may fail open prior to permitting continuous firing by that particular jet. Although six series fuel valves and six series oxidizer valves (total of 12) could fail open to permit continuous firing by any jet, its effect would be countered by an approximate 50 percent duty cycle firing by the two jets firing in the opposite direction until the failed pro-propellant source is exhausted (or an isolation valve is closed).

Although Fail Op, Fail Safe may be interpreted as being adequate for the RCS system, it would seem that the electronics in the form of the number of preprocessors should generally approach the redundancy of the valves. A single location of triplicate preprocessors with each capable of servicing all four stations could be considered. However, a casualty separation capability should be afforded (one on one side of a bulkhead and two on the other side) to be consistant with the assumed RCS station locations on the ends of the Space Station. Two end-of-vehicle locations for preprocessors may be considered with each preprocessor being dual and capable of servicing two RCS stations. Four (4) dual preprocessor locations near each RCS station may be considered with each preprocessor servicing only one RCS station. Multilocations of preprocessors may require some duplication of computations. However, a significant reduction in the number of monitoring and isolation signals per processor would be realized. The number of preprocessor locations for this study will consist of four locations, one set of preprocessors per engine station.

The RCS redundancy in Figure 2-2 assumes dual preprocessors in four loca-tions (total of 16) for the four RCS stations. In addition, quad electronic redundancy is assumed for the source quad valves. Thus, for Fail Op conditions, the electronic redundancy is four corresponding to the assumed number of RCS preprocessors. The redundancy for Fail Safe additionally includes three of the quad electronics associated with the source valves.

The redundancy depicted in Figure 2-2 may be further increased. For example, if the preprocessor computations are allocated accordingly, and if transmission capability is included from the OAS and SIRU to the CMGs or RCS, then control system operation may be available irrespective of the status of the digital computer. In addition, hard wire connections may be made with a similar objective toward manual or backup automatic control.

2.4 G&C REQUIREMENTS

The G&C system must conform to resupply cycle times of four months initial resupply availability and for durations of six months thereafter. Although parts or module replacement is permissible, the system should be condusive to the 10-year Space Station lifetime.

2.4.1 General Requirements – Unmanned

No stated requirements exist for the Space Station G&C system prior to transferring control in orbit from the S-II booster G&C system. This transfer of control is to be accomplished with no hard wire connections. Requirements are anticipated for a G&C system checkout (principally for the computer) prior to lift-off. However, prelaunch checkout/system monitor would be a limited portion of the on-orbit operational system monitoring requirements. Therefore, prelaunch checkout is considered an integral part of the total on-board checkout system, which is out of scope for this study.

Immediately prior to transfer of control, the Space Station G&C system will require activation and checkout. After control is transferred, the G&C system will perform functions of attitude control and navigation in an orbital coast condition. References for attitude control may consist of the initial reference upon control transfer (inertial or local level) as well as other inertial or local level references to be executed upon subsequent command. The navigation function is to perform orbit determination in a primary role and to receive ground track update as an incidental role.

The duration of unmanned operation is expected to be less than two days. Upon command from an approaching Logistics Vehicle, the Space Station will hold the commanded attitude (probably fine attitude hold) preparatory to docking and transition.

2.4.2 General Requirements – Manned

After manned entry to the Space Station, an interval of familiarity and checkout will require the G&C system to perform attitude control and navigation during orbital coast, similar to unmanned operation but additionally providing for manual inputs.

After the familiarization interval, the S-II undergoes end-to-end trans-position under manual control. Next, the S-II and Space Station combination is deployed and spun-up with the G&C systems only requirement during spin-up being to provide and maintain commanded spin rate. The combination is spun for artificial "g" assessment during the first month of manned operation. During this time the G&C system is to provide balance control for wobble damping, maintain commanded spin rate (approximately 4 RPM), and correct for spin axis precession within prescribed limits. The G&C system is not required to perform navigation or state vector determination of Experiment Modules during the

artificial "g" period. After the combination is despun and retracted, a zero "g" configuration under manned operation will commence. In the event the S-II is subsequently subject to disposal, the disposal velocity vector computation may be required from the G&C system.

The manned - zero "g" operation will consist of orbital coast with the G&C system performing functions of attitude control and navigation. Attitude reference may include local level (earth), inertial, and solar inertial. In addition, the G&C system shall perform functions of state vector determinations of co-orbiting vehicles, calculations of transfer impulses pursuant to rendezvous or dispatch, steering commands to incoming vehicles during rendezvous, and translation (steering) and attitude commands to docking vehicles. Also, the G&C system shall compute and issue station-keeping commands (for orbital makeup) to the reaction jets. Since the force levels will be relatively small and station-keeping may be considered as continuous; being inhibited only by on-board experiments, convenience of system momentum budgets, or convenience of orbital angle; it is considered as a task to be performed during orbital coast rather than to be defined as a separate mode.

2.4.3 Subsystem Requirements

In an inclusive sense, the subsystem requirements shall be determined to fulfill the G&C system requirements. Discussion of redundancy aspects will be deferred to Section 2.5. However, the reconfigurable computer redundancy requirements have been defined. Sensor and actuation subsystem redundancy has been generally defined in addition to providing for degrees of functional redundancy.

In conjunction with the preceding discussion of General Requirements, Table 2-4 is presented to show the allocation of Subsystem Requirements in the form of a G&C Requirements Matrix. The G&C subsystem equipment list is included in Table 2-4 with the exception of the computer which is required to perform the listed G&C Functions. Corresponding to the G&C Functions, which are listed in the first column, various Mission Modes and PHases are listed in the other columns and are self-explanatory. The need for the G&C Function to be performed during each Mission Mode or Phase is indicated by an "X" as an operational requirement using G&C assigned subsystem equipment or by a "D" as an operational requirement using other equipment directly addressable via the Data Bus. The equipment which must operate during each Mode or Phase is listed by number as the last row of the matrix.

Although not specifically identified in Table 2-4, all of the Mission Modes and Phases may be generally categorized as Orbital Coast as per previous discussion.

The G&C computer functions are considered totally inclusive regardless of subsystem mechanization approach with the exception of "Compute Strapdown Equations" which would not be required in the event an inertial platform were

Table 2-4. G&C Requirements Matrix

G&C Functions (Computer)	Mission Modes and Phases	Activate, Checkout and Transfer Control	Attitude Maneuvers and Acquire Orientation	Local Level (Coarse and Fine)	Inertial (Coarse and Fine)	Art "g" Balance Control	Rendez. and Docking	Support Detached Vehicles	S.S. Station Keeping
		Un-Manned		Attitude Hold — Manned and Unmanned		Special Manned Phases			
Receive and Store Modes		X	X	X	X	X	X	X	
Process Commands/Updates		X	X	X	X	X	X	X	X
Perform Status Monitoring		X	X	X	X	X	X	X	X
Point Sensors for Search			X	X	X				
Acquire and Track Objects			X	X	X				
Read Sensors		X	X	X	X	D	D	D	X
Compute Strapdown Equations		X	X	X	X	X	X	X	X
Compute Attitude Error		X	X	X	X	X	X	X	X
Compute Navigation			X	X	X		X	X	X
Issue Actuation Commands		X	X	X	X	X	X	X	X
Issue Station Keeping Commands				X	X			X	X
Monitor and Issue Momemtum Dump				X	X	X		X	X
Compute State Vectors				X	X		D	D	X
Provide Align. Reference			X	X	X		D	D	X
Provide Art. "g" Balance Control					X	D			
Provide Rendezvous Aids				X	X		D	D	
Provide Docking Aids				X	X		D	D	
Provide Dispatch Aids				X	X			D	
Provide Required Reconfiguration		X	X	X	X	X	X	X	X
Equipment		1,3,4	1→4	1→4	1→4	1,3 4,7	1→6	1→4 D	1→4

NOTE: "X" indicates operational requirement

"D" indicates information available on Data Bus

Equipment List

1	SIRU	5	Rendezvous Sensors (D)
2	OAS	6	Docking Sensors (D)
3	CMGs	7	Balance Sensors (D)
4	RCS	D	Data Bus Information

implemented. The OAS, which includes both star trackers and horizon scanners, is listed as a functional subsystem entity. The station keeping column would functionally require only the SIRU and the RCS. However, the OAS is listed in keeping with the routine orbital coast mode and the CMGs are listed as a conjunctive momentum dump activity.

The required functions under the Special Manned Phases in Table 2-4 are listed for completeness to avoid any misunderstanding. However, it is felt that greater clarity could be provided relative to including new or by-passing unnecessary computer routines if these column entries included only "Delta" or different G&C functional requirements.

2.5 G&C SYSTEM CONFIGURATION

The G&C System consists of a reconfigurable central computer, four primary subsystems and associated computational requirements pertaining to three additional subsystems. In addition, communication, data delivery, and command processing functions are required on a Data Bus access with the "central data, display, and checkout computer complex" (information management system). Both the internal and external G&C system signal transmission is to be accomplished via a Data Bus.

The general layout of the baseline G&C system configuration is shown in Figures 2-3a and 2-3b which are drawn to be end-to-end-connected. The G&C Digital computers (A) and the four primary subsystems - SIRU (B), OAS (C) CMGs (D), and RCS (E) are shown as being interconnected by the Data Bus. The three additional subsystems are shown as Other Subsystems (G). The configuration interface with external G&C functions is shown as the Information Management System/Computer (F). In practice, data generation and data reception by Function G may be performed by Function F. The symbology of External Systems is shown in Figure 2-3 only from the standpoint of general interest. A single data bus system may be employed rather than two data buses as shown.

The digital computer is to have modular construction and is to be re-configurable in event of failure or priority of command. It will be configured to exercise various computing routines as per the G&C Requirements Matrix in Section 2.4 (Table 2-4). Although the approach to the G&C computer configuration will remain unchanged, certain computational functions are subject to trade-off. This trade-off concerns the possibility of performing selected computational functions in the G&C digital computer or in preprocessors located with the separate subsystems. A list of computational allocation trades is shown by the second listing on each of the subsystems including the computer. The computer is assumed to provide at minimum, Data Bus control, subsystem power distribution, and subsystem monitoring functions. The reconfigurable extent of the G&C central computer is to provide Fail Operational, Fail Operational, Fail-Safe capability. This requirement is interpreted to result in a four-computer configuration.

The four primary subsystems will require interface units (as parts of the G&C system) for data bus access.

Fig. 2-3a. G and C Baseline Configuration/Definition

External Systems

Ground Track/Communi-
cations
Logistics Vehicle
Experiment Modules
Orbital Taxis
Landmarks

G - Other Subsystem

Rendezvous Sensor
Docking Sensors
Balance System

Data Bus

Interface
Unit

Interface
Unit

Interface
Unit

Interface
Unit

B - SIRU - 1 Location

I - Equipment
a. 6 gyros
b. 6 accelerometers
c. Dual electronics
d. Dual power supplies

II - Computational Allocation Tradeoffs
a. Filter Instrument Outputs
b. Failure Detection and Transformation
to Body Coordinates
c. Direction Cosine Matrix Update
d. Direction Cosine Matrix Orthogonali-
zation
e. Generation of Attitude Error Signals

C - OAS (Optical) - 1 Location

I - Equipment
a. 2 gimballed platforms
b. 2 star tracker heads/platform
c. 2 horizon scanners/platform
d. Dual redundant electronics
e. Dual power supplies

II - Computational Allocation Tradeoffs
a. Failure Detection
b. Compute Horizon Sensor Scanning Angles
c. Processed Measured Data
d. Compute Horizon Sensor Pointing Angles
and Rates
e. Compute Star Tracker Pointing Angles
and Rates
f. Make Star Selection

D – CMG – Location

I – Equipment
a. 3 – Twin axes gyros
b. Dual electronics
c. A/D and D/A conversion

II – Computational Tradeoffs
a. Control Mode Detection
b. Torque Error Computation
c. Momentum Error Computation
d. Desaturation
e. Failure Detection and Isolation
f. Reconfiguration

E – RCS (Jets) – 4 Locations

I – Equipment
a. 4 quads of 4 jets
b. 8 primary valves/jet
c. Dual quad supply valves
d. Dual electronics
e. A/D and D/A conversion

II – Computational Tradeoffs
a. Control Mode Detection
b. Torque/Force Computation
c. Engine Valve Control
d. Failure Detection
e. Failure Isolation
f. Reconfiguration

Interface Unit

Interface Unit

Interface Unit

Interface Unit

Interface Unit

Interface Unit

F – Information Management System

A – Reconfigurable Computers

I – Equipment – (To be determined)

II – Computational Allocation Trades
a. B II Functions
b. C II Functions
c. D II Functions
d. E II Functions

III – Fixed Computations
a. Balance Control
b. Docking
c. Rendezvous
d. Executive
e. Diagnostics
f. I/O
f. Utility Functions

Fig. 2-3b. G and C Baseline Configuration/Definition

Although not explicitly indicated in Figure 2-3, the four primary subsystems will have some form of computational preprocessors interconnecting the subsystems with their respective interface units. This interconnection may be integral or modular. However, the total extent of preprocessing is subject to trade-off.

The function of inertial reference instruments is represented by the SIRU (Strapped-down Inertial Reference Unit) subsystem which consists of six (6) gyros and six (6) accelerometers (pulse-rebalance) mounted in a unique symmetrical pattern (dodecahedron). The accelerometers, being sensitive to a "g" environment, are applicable for Space Station usage during artificial "g" periods. The SIRU is configured to contain a failure detection and isolation scheme as a result of a computational process. Continued system operation occurs with up to three out of six gyro failures. However, the third failure is ambiguous. Normal application of the SIRU gyros is for short-term inertial reference or smoothing of other instrument outputs with the long term gyro drifts being compensated within the computer by inertial instrument, such as star trackers, measurements. The measurement data are used for attitude and navigation updates.

Functions of inertial measurements and local body (earth reference) measurements are represented by the OAS (Optical Attitude Sensors) which consist of redundant star trackers and redundant horizon scanners. Digital pickoffs of the gimbal angles are assumed.

Functions of providing mass conservative momentum interchange are represented by the CMGs (Control Moment Gyros). This configuration represents three double-gimbal CMGs for application to cyclic control events during attitude hold limit cycle operation and for very low rate attitude maneuvering. Momentum dump capability is provided by the reaction jets with associated control logic. The CMG subsystem is provided with status monitoring and failure isolation. The three CMGs are assumed configured for zero net angular momentum when they are aligned to their gimbal nulls since the majority of the mission time consists of local vertical or artificial "g" operation.

Functions of providing control torques of the mass-expulsion type are represented by the reaction jets of the RCS (Reaction Control System). In addition, the RCS provides nominal translation forces (with suitable logic) for station-keeping purposes to provide for orbital makeup. The RCS is distributed to always provide pure couples (provided no jets have failed) about the three attitude control axes. The number of jets are sixteen (four locations of four jets each) with a possibility as high as twenty-one. This possibility would represent no appreciable difference in requirements other than for purposes of status monitoring and isolation. A bi-propellant feed source is to be provided to each jet. Considerations for further redundancy (beyond the couples) focus on the control valves. The most complex realistic redundancy approach (included herein) uses quad valves in each fuel and oxidizer line to each jet as well as in each of the dual supply lines. The required status monitoring and failure isolation is a function of the number of jets, valves, and valve drivers. The RCS performs functions of CMG override (large errors), torque generation for nominal attitude maneuver rates, CMG momentum dump, and translation forces for station keeping.

Equipment redundancy has been discussed in connection with each of the four subsystems. In addition, functional redundancy is present. As an example, redundant sensor signal availability exists in each of the following forms: stellar inertial, strapdown inertial, and earth reference. Therefore, if the total availability were lost in one of the forms, continued G&C system operation could result, though possibly reduced accuracy. In a similar vein, the CMGs and RCS have functional redundancy for control torque generation. If the CMGs should totally fail, continued G&C system operation would be provided by the RCS.

The G&C computational requirements associated with the three additional subsystems, Rendezvous, Docking, and Balance System (denoted as Function G in Figure 2-3), do not include subsystem interface requirements as a part of the G&C system. Rather, these data are simply assumed available for transmission and reception on the Data Bus under the control of the G&C computer. The G&C computer shall be configured to perform computations to support rendezvous and docking of incoming vehicles. Also, computations will be performed for the balance system during artificial "g" periods of operation.

2.6 SYSTEM MECHANIZATION

The system mechanization is the functional mechanization of the mission modes from which the equations, signal interface, control and monitoring requirements are generated for the system. The overall mechanization is defined as the top flow diagram. This diagram, Figure 2-4, identifies the major functions to be performed by the G&C computing system and is in conformance with Section 2.3 System Approach. The details (functional modules) of the mechanization are identified by first and second level flow diagrams and/or the mechanization equations explicitly.

The mechanization, as shown in Figure 2-4, does not include testing and reconfiguration of the G&C computer system to effect the Fail-Op, Fail-Op, Fail-Safe criteria.

The mechanization is designed for ease of performing computational allocation trade-off studies. That is, in the case of the SIRU, OAS, CMGs, and RCS, the major program modules are discretely subdivided such that implementation of submodules may be performed at the subsystem level or in the central computer and cascaded together.

2.6.1 Mission Phases

Three major phases of the mission have been identified per this mechanization. These include the Prelaunch, Boost, and Orbital Coast phases. The computational requirements for the Prelaunch and Boost phases are not considered part of this study. However, it is anticipated that an interface with the ground station command center will be required during prelaunch for system test and checkout. This requirement will impose, primarily, a memory requirement with no added imposition on duty cycle requirements. The magnitude of the memory
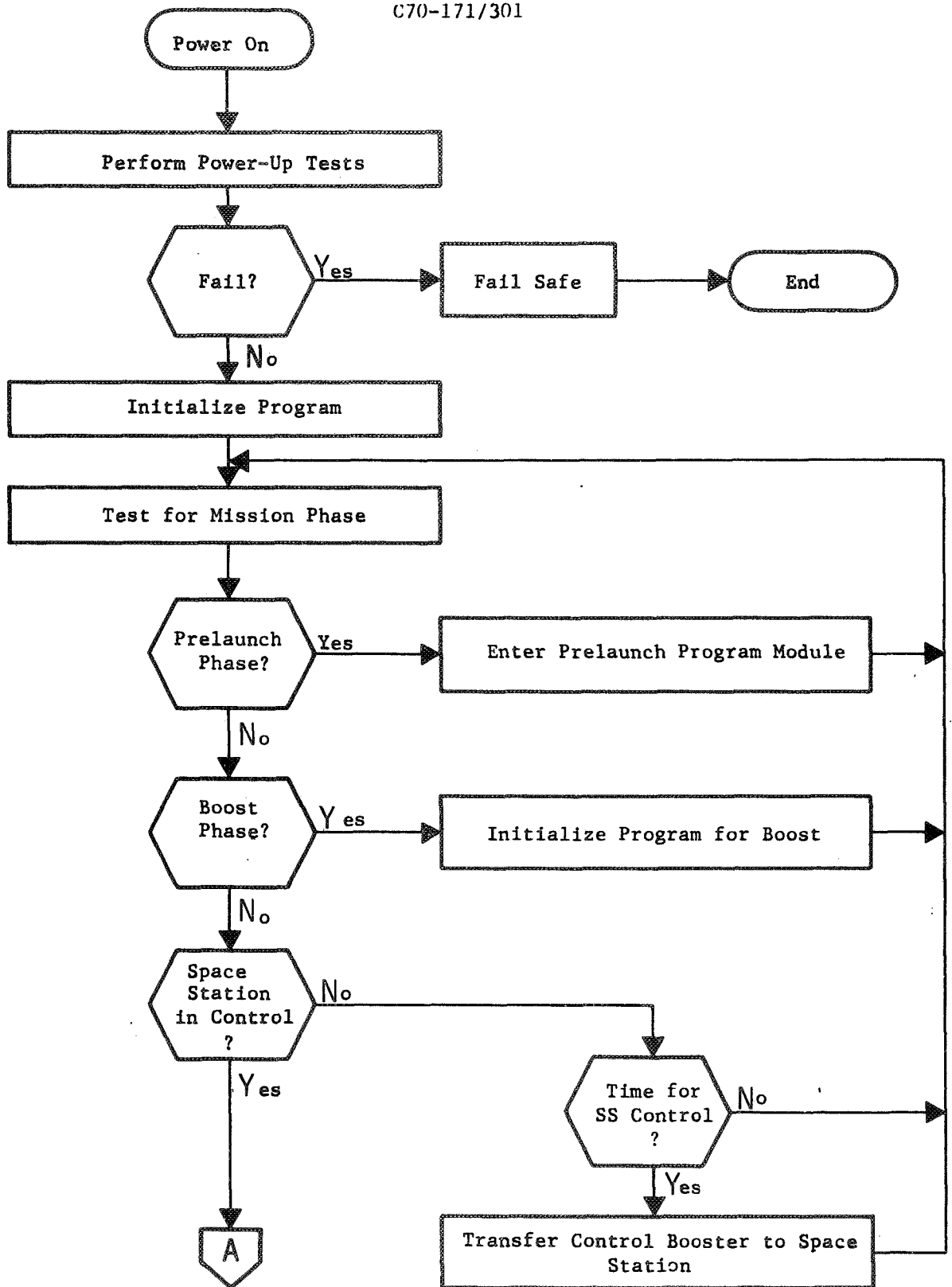
Fig. 2-4. G&C Top Flow Diagram

A

```
┌─────────────────────────────┐
│        Mode Control         │
├─────────────────────────────┤
│ Set Real Time Mode Control  │
│    Flags                    │
└─────────────────────────────┘
```

```
┌─────────────────────────────────────┐
│        Attitude Determination        │
├─────────────────────────────────────┤
│ Initialize (Coarse Align)           │
│                                     │
│ Determine Status of SIRU and OAS    │
│                                     │
│ Reconfigure as Required             │
│                                     │
│ Compute and Update Direction Cosines:│
│     (a) Gyros                       │
│                                     │
│     (b) Star Tracker                │
│                                     │
│    *(c) Sun Sensor                  │
│                                     │
└─────────────────────────────────────┘
```

```
┌─────────────────────────────────────┐
│       Navigation Determination       │
├─────────────────────────────────────┤
│ Determine Status of Horizon Scanner │
│                                     │
│ Reconfigure as Required             │
│                                     │
│ Compute and Update Orbital Position:│
│     (a) Horizon Scanner             │
│                                     │
│    *(b) Landmark Tracker            │
│                                     │
│    *(c) Ground Station              │
│                                     │
│    *(d) Manual Update               │
│                                     │
└─────────────────────────────────────┘
```

B

(*Not presently included but may be desirable)

Fig. 2-4. (continued)

Fig. 2-4. (continued)

```
                        ┌───┐
                        │ C │
                        └───┘
                          │
                          ▼
              No       ╱──────────╲
           ◄───────────   Time for  
                        ╲ EM Update? ╱
                         ╲──────────╱
                              │
                             Yes
                              │
                              ▼
        ┌──────────────────────────────────────┐
        │      Experimental Module Update       │
        ├──────────────────────────────────────┤
        │                                        │
        │   Read and Command RR                  │
        │   Compute Errors                       │
        │   Update State Vectors                 │
        │                                        │
        └──────────────────────────────────────┘
                              │
                              ▼
                         ╱──────────╲
                        ╱   Time to   ╲
                        ╲  Dispatch   ╱
                         ╲   Taxi    ╱
                    No    ╲────────╱
                              │
                             Yes
                              │
                              ▼
        ┌──────────────────────────────────────┐
        │            Taxi Dispatch              │
        ├──────────────────────────────────────┤
        │                                        │
        │   Provide Inertial Reference Unit      │
        │      Alignment                         │
        │                                        │
        │   Compute ΔV Commands                  │
        │                                        │
        │   Compute Separation Commands          │
        │                                        │
        └──────────────────────────────────────┘
                              │
                              ▼
                           ┌───┐
                           │ D │
                           └───┘
```

Fig. 2-4. (continued)

```
                        ┌───┐
                        │ D │
                        └─┬─┘
                          ▼
                    ╱─────────────╲
               No  ╱      In       ╲
           ◄──────    Rendezvous    
                    ╲     Mode      ╱
                     ╲─────────────╱
                          │
                          ▼ Yes
```

Terminal Rendezvous
Compute and Output Rendezvous Radar
Read Sensor Data
Compute and Output Thrust Vector Command Signals
Monitor for Docking Window

```
                    ╱─────────────╲
               No  ╱      In       ╲
           ◄──────    Docking       
                    ╲    Mode       ╱
                     ╲─────────────╱
                          │
                          ▼ Yes
```

Docking Mode
Perform Rendezvous-to-Docking Transition
Read Sensor Data
Compute and Output G Degree-of-Freedom Commands
Monitors for Contact

```
                        ┌───┐
                        │ A │
                        └───┘
```

Fig. 2-4. (continued)

requirement will be directly proportional to the detail of fault detection and isolation required prior to launch and the subcontractors methodology for each subsystem. The requirements during the actual boost phase are assumed to be little or none, since the computer is assumed to be shut down or idle during boost. The requirements for the transition from the boost phase to orbital coast are of the "one-shot" type and consequently will require only added memory (i.e., no effect on duty cycle).

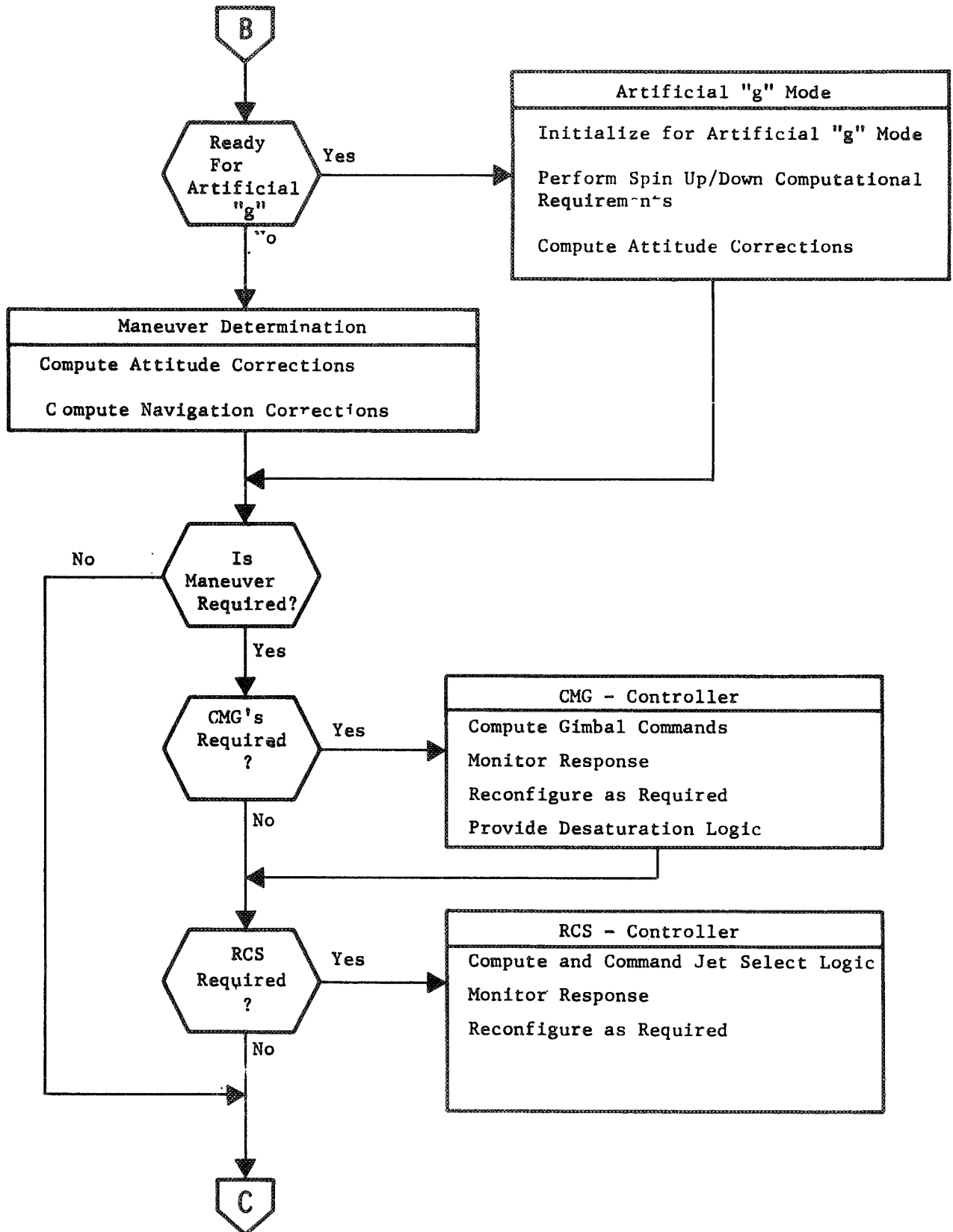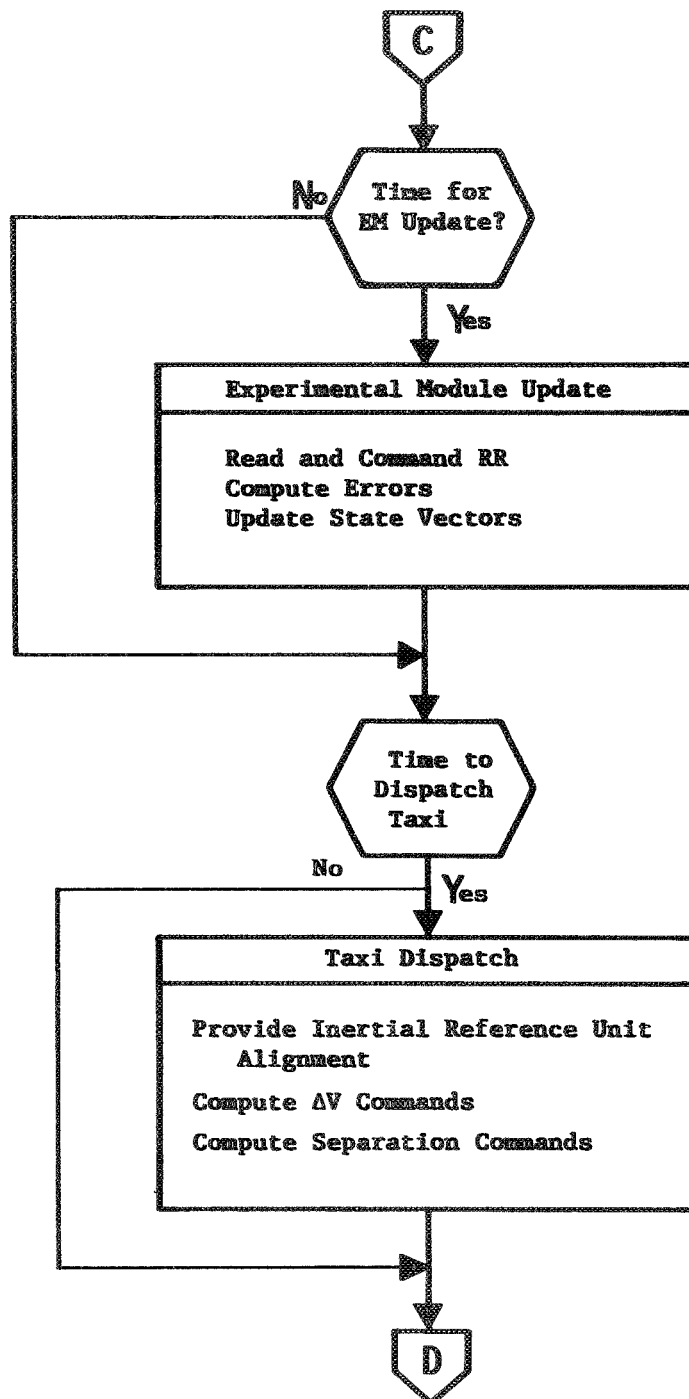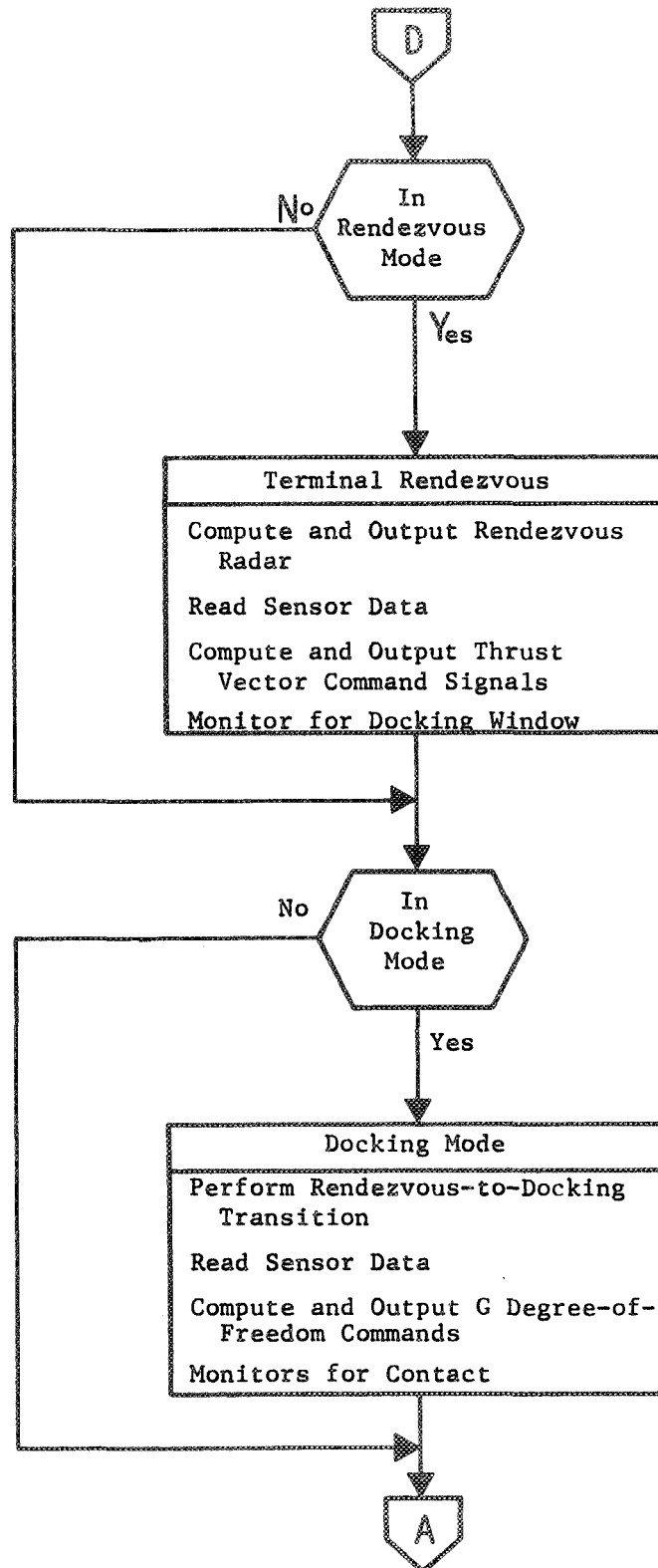The orbital coast phase is the phase of primary concern for this study and is used to estimate the basic memory size, speed, and signal interface requirements for the computer system. Furthermore, there is no differentiation between the unmanned mode and the manned mode for this phase since the unmanned mode is considered a subset of the manned mode. The orbit coast phase begins with the space station in full control as per Figure 2-4 ("Space Station in Control? - Yes") and performing the functions mechanized.

2.6.1.1 Mode Control - This module can be considered a part of the program executive function inasmuch as providing program control flags for executing the various software modules. These flags may be set by certain conditions sensed throughout the program flow-thru or by man machine linkage as applicable. That is, mode control implies such functions as rendezvous, docking, artificial "g"s, steering or maneuvering commands, etc.

2.6.1.2 Attitude Determination - The fundamental purpose of this function is to provide the direction cosines for attitude control of the space station/ logistics vehicle. For this study, control is provided in both inertial and local level. The two subsystems used in performing this function are the SIRU (Strapdown Inertial Reference Unit) and OAS (Optical Attitude Sensor).

A first level flow diagram for attitude determination is shown in Figure 2-5. This diagram presents the various subfunctions in performing attitude determination and is basically self explanatory. For greater detail, the reader is referred to the sixth monthly progress report, "Computational Requirements Analysis for SIRU and OAS."

2.6.1.3 Navigation Determination - The purpose of this function is to estimate the space station position and velocity relative to the reference system. Again, the SIRU and OAS subsystems are used in computing these data. The first level flow diagram depicting the mechanization of this function is shown in Figure 2-6. Second level diagrams for the modules FDIST and FDHM are shown in Figures 2-7 and 2-8 respectively. All three of these diagrams are basically self explanatory. For further information, refer to the sixth monthly progress report.

2.6.1.4 Maneuver Determination - This function generates the CMGs and/or RCS steering command signals for attitude and/or navigation corrections. The control law employed for this study uses proportional plus rate and is based on the phase plane relation to minimize limit cycling.

Start

Attitude
Initialized — Yes → Filter Gyro Outputs — EQFGO

No ↓

Initialize Attitude

Time to Check if SIRU Failed? — Yes → Perform Check on SIRU. Any Failures? — Yes → Possible To Reconfigure? — No

No ↓   No ↓   Yes ↓

Reconfigure Transformation Matrix ←   Set Flag

EQFAG

Correct $\overline{\Delta\theta}$ With $\overline{\Delta\epsilon}$ (Estimated Gyro Drift Rates). Update Direction cosine Matrix C_I^B — No ← Time for Star Tracker Measurement?

EQUPC

Yes ↓

Make Star Selection from Catalog Including Search Angle — EQSS

Time to Orthogonalize C_I^B

Orthogonalize C_I^B

EQORC

Generate Pointing Angles and Rates μ_c, σ_c — EQSPAR → Make Measurement μ_m, σ_m

Remeasure Angles to Star Using same or Different Non-failed Star Tracker

Compute New Estimate of $\overline{\Delta\psi}$, $\overline{\Delta\epsilon}$. Correct $\overline{\Delta\theta}$, with $\overline{\Delta\psi}$ — EQUPAS ← Yes ← & $|\mu_c - \partial_m| < \epsilon$? $|\sigma_c - \sigma_m| < \epsilon$? — No → Are there Valid Measurement Remaining? — Yes

No ↓

Compute Attitude Errors - Angles and Angular Rates — EQAE

Set Flag

EQSTFD

Exit

Fig. 2-5. Attitude Determination Flow Diagram – First Level

Start

Process
Accelerometer
Data   EQAUD

N ⟨ Should Space
Station State
be Updated? ⟩ Y   Update Space Station   FDIST
State and Covariance   EQIEQ
Matrix with Time   EQPPV

N ⟨ Should
Horizon Measure-
ment be Made? ⟩ Y   Compute Horizon Sensor
Pointing Angles and Rates;
Angle to Horizon, θ_c EQHP

Measure
Angle to   FDHM
Horizon, Z   EQSHP
EQPHM

Update Space
Station State
Based on
Measurements

EQSUM

N ⟨ $|\theta_c - Z| < E_T$? ⟩

Remeasure
Angle to
Horizon Using
Same, or
Different, Non-
failed Horizon
Sensor

Y

Set
Flag

N ⟨ Are There
Valid Measure-
ments Remaining? ⟩ Y

FDHM
EQNHP
EQPHM

Exit

Fig. 2-6.   Navigation Flow Diagram - First Level

Start

$$\begin{array}{|l|}\hline \text{Update } \bar{r}_{con}, \bar{V}_{con} \text{ to Time} \\ \text{t Using Kepler's 2 Body} \\ \text{Equations} \qquad\qquad \boxed{\text{EQKP}} \\ \hline\end{array}$$

Update $\bar{r}_{con}$, $\bar{V}_{con}$ to Time
t Using Kepler's 2 Body
Equations

EQKP

Integrate Deviations
$\bar{\delta}(t)$, $\bar{v}(t)$ to Time t
Integrate C_x to Time t

EQIEQ

$F(t) = \bar{r}_{con}(t) + \bar{\delta}(t)$
$\bar{V}(t) = \bar{V}_{con}(t) + \bar{v}(t)$

Time to
Rectify
Orbit?

Yes

$\bar{r}_{con}(t) = \bar{r}(t)$
$\bar{V}_{con}(t) = \bar{V}(t)$
$\bar{\delta}(t) = \bar{v}(t) = \bar{0}$

No

Determine Coefficients for
Polynomial Representation
of $\bar{P}$, $\bar{V}$

EQPPV
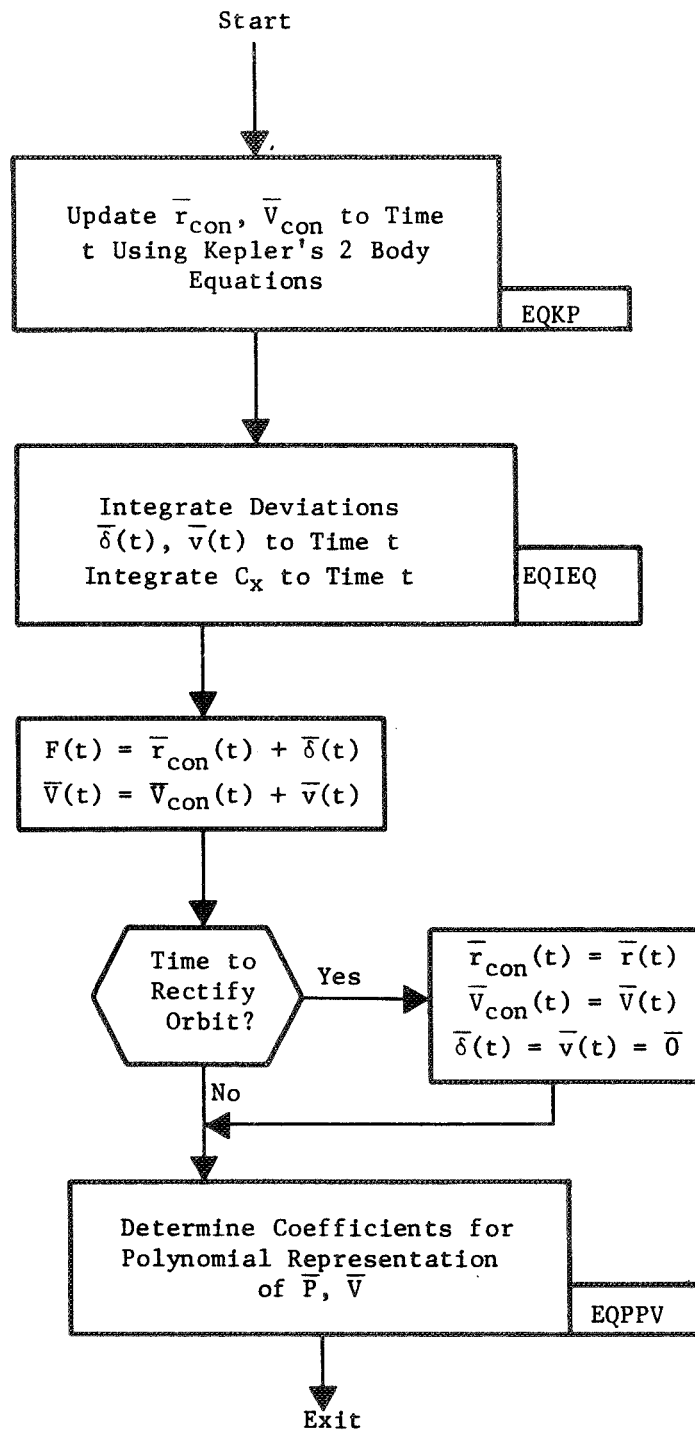
Exit

Fig. 2-7. Flow Diagram for State Integration –
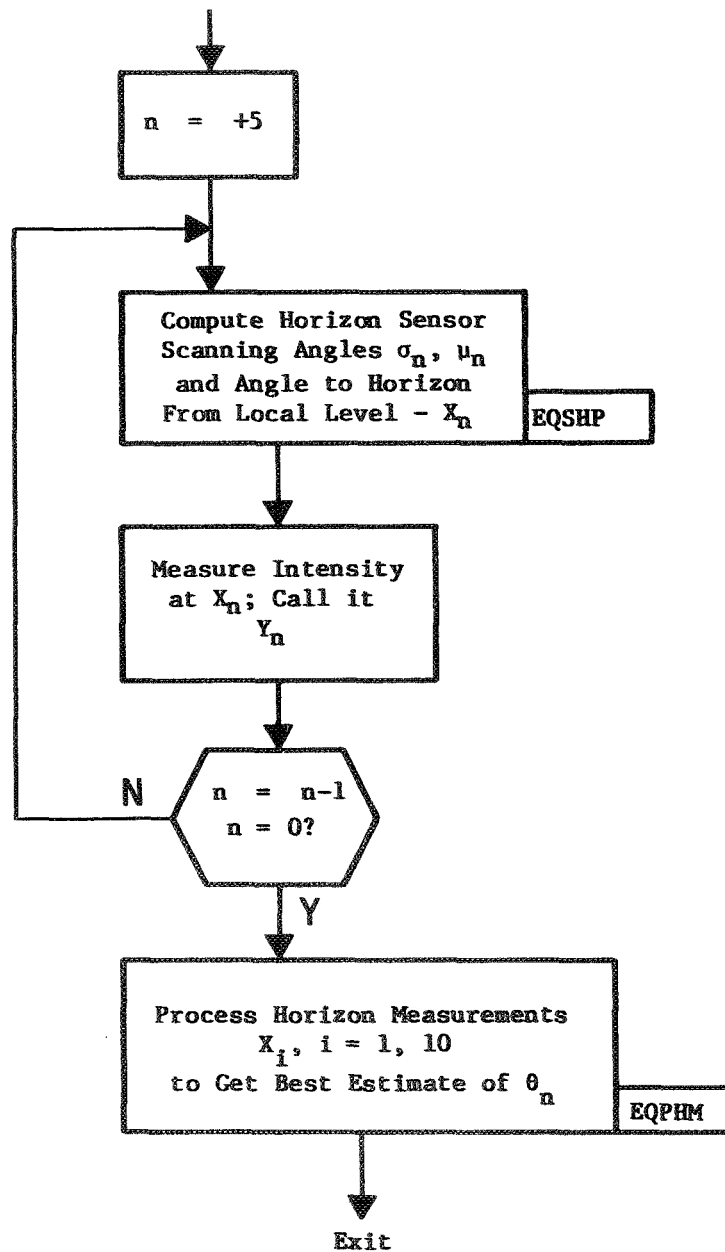FDIST – Second Level

Fig. 2-8. Horizon Sensor Measurement Flow Diagram –
FDHM – Second Level

The Maneuver Determination function provides for various steering modes including Hold Attitude (fine or coarse), Low Rate Maneuver, High Rate Maneuver, and CMG Desaturation Maneuver.

2.6.1.5 Artificial "g" Mode – The purpose of this function, as shown in Figure 2-4, is to perform both the static and dynamic computational requirements necessary for balance control. Second level diagrams for this function are presented in the form of equations only, Section 2.7 – "Computational Require-ments."

The significance of this function is primarily to give an overall sense of complexity for sizing the G&C computer/data bus system. The level of fault detection and isolation for this function is limited to a simple interface.

2.6.1.6 CMG Steering – The program module "CMG Steering" is mechanized to generate the appropriate CMG torque and momentum errors for the attitude control of the space station, and provide for desaturation of the gyros, failure detection and isolation, and corresponding CMG reconfiguration implementation. The first level flow diagram for performing these functions is shown in Figure 2-9. For further details the reader is referred to the sixth monthly progress report "Computational Requirements Analysis for CMGs and RCS."

2.6.1.7 RCS Steering – The purpose of the RCS Steering module is to provide the necessary logic and computations to compute the torque and force commands, the engine valve control, and provide failure detection, isolation and reconfigura-tion of the reaction control system. The first level flow diagram showing the relation and logic decisions for implementing these functions is presented in Figure 2-10. The diagram is basically self explanatory, however, further information may be gained from the sixth monthly progress report.

2.6.1.8 EM Update – The purpose of this function is to provide the necessary logic and computations to update the state vecotrs of the experiment modules (2 modules plus 1 taxi). The exact mechanization for this function is outside the scope of this study, however, for purpose of estimating, the space stations state vector computation in combination with update measurement equations for the rendezvous radar was used.

2.6.1.9 Module Dispatch – The purpose of this function is to provide the capability to align a simple inertial reference on board the taxi vehicle and provide appropriate commands to transport the experiment module to and from the space station via the taxi. Here again, no exact mechanization is provided. A gross estimation was made using alignment procedure data from previous studies combined with simplified command and control equations for a co-orbiting vehicle.

2.6.1.10 Terminal Rendezvous – The purpose of this module is to compute the rendezvous radar look angles, process the return angles, and compute the command and control signals necessary to position the external vehicle (shuttle/taxi) in a pre-docking station keeping window. An exact mechanization for this function is outside the scope of this study; however, a gross estimate utilizing Apollo information (see Section 2.7 – Terminal Rendezvous) and simplified equations was performed.

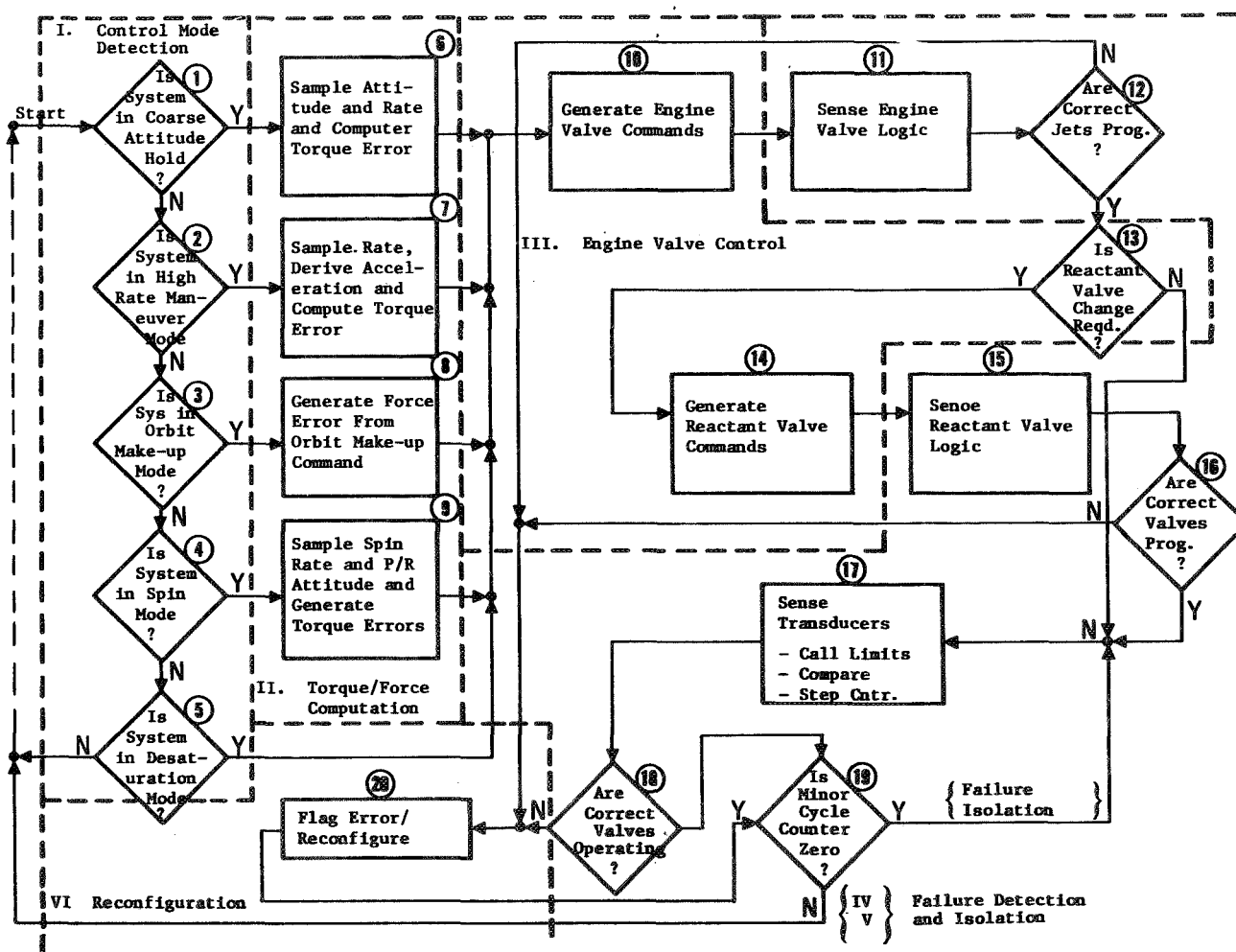Fig. 2-9. First Level CMG Steering
Computation Flow Diagram
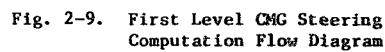
Fig. 2-10. First Level RCS Computation
Flow Diagram

2.6.1.11 Docking - The Docking module is mechanized to execute the necessary logic and computations for performing the transition from rendezvous to docking (and vice versa), and establish appropriate monitoring to provide the command and control necessary to docking the external vehicle. Again, these data were estimated based on the automatic docking procedure described in Section 2.7, "Computational Requirements."

2.7 COMPUTATIONAL REQUIREMENTS

This section is concerned with the computational requirements peculiar to the central (reconfigurable) computer complex only. Processing requirements at the subsystem level are presented in Section 2.9, "Computational Allocation Trade-Offs." The requirements presented in this section deal with the maximum requirements (minimum preprocessing at the subsystem level) and the minimum requirements for the four subsystems specified for detail analysis and trade-offs in accordance with the work statement (RCS, CMGs, SIRU, and OAS), where minimum implies maximum subsystem preprocessing. To accommodate this approach, the computational requirements are grouped into two categories. That is, one category concerned with performing detailed computational allocation trade-offs between the subsystems of concern and the central computer complex, while the second category is not. The first category involves the RCS, CMGs, SIRU, and OAS and includes the following major program modules:

a. Attitude Determination

b. Navigation Determination

c. Maneuver Determination

d. CMG Control

e. RCS Control

While "Maneuver Determination" does not change for various allocations, it is included in this category for consistency. The remaining program modules deal with outer-loop command and control functions and are categorized as follows:

a. Experimental Space Module Updates

b. Taxi (co-orbiting shuttle) Alignment

c. Terminal Rendezvous

d. Docking

e. Balance Control

Again, these functions are estimated for the maximum value case only and will not be considered as part of the trade-study under this work statement.

For convenience and because the computer housekeeping functions are considered fixed for any variation of the first category, these functions are also included in the second category. Such functions include the executive program, computer diagnostics, utility routines (sine, cosine, $\tan^{-1}$, etc.) and I/O storage and command functions. The requirements for the case having minimum preprocessing at the subsystem level are given in Table 2-6. The requirements for the functions performed in the first category are:

Memory Storage = 17,400 words

Speed = 794,800 short operations/sec

The memory storage is the combined sum total of instructions, constants and variables and implies 16 bit words. Speed is the required short and long computer operations (long = 2 short) necessary to perform the functions.

Applying the same format the requirements for the category two functions are given as follows:

Memory Storage = 21,200

Speed = 79,200 short operations/sec

In viewing Table 2-6, the requirement specified as "Background" includes an immediate memory storage requirement with no impact on duty cycle. In essence, "Background" implies computational requirements scheduled on a cycle much greater than once per sec (e.g., once every 1000 sec). A design allowance for background functions and for periodic functions such as rendezvous and docking are assigned to be performed during the 20 percent duty cycle allowance provided as Item 15 (Background) in the Table. Typical Background computations include, for example,

a. Star Selection (10^{-3} times/sec)

b. Star Pointing (10^{-3} times/sec)

c. Star Tracker Failure Design (10^{-3} times/sec)

d. Direction Cosine Orthog. (10^{-2} times/sec)

e. Attitude Update (10^{-3} times/sec)

The twenty percent duty cycle allowance is also designed to accommodate reconfiguration requirements which are not exercised during normal duty cycle operations.

The estimated computational requirements for the case having maximum preprocessing at the subsystem level is given in Table 2-5. In this case, only those functions dealing explicitly with the SIRU, OAS, CMGs, and RCS are examined, with the carry-over of requirements from Table 2-6 for the remaining functions. It must be noted that in providing this estimate little consideration is given here with respect to the size and/or speed necessary at the subsystem

Table 2-5. Estimated Computational Requirements Having
Maximum Preprocessing

Program Module	Storage Requirements	Computer Operations		Execution Rate (sec)	Duty Cycle (ops/sec)	
		Long	Short		Long	Short
1. Attitude Determination						
Fixed Rate	400	100	1,100	100	10,000	110,000
Background	1,700	–	–	–	–	–
2. Navigation Determination						
Fixed Rate	300	50	300	100	5,000	30,000
Background	2,600	–	–	–	–	–
3. Maneuver Determination						
Fixed Rate – A	900	170	900	20	3,400	18,000
Fixed Rate – B	200	40	100	200	8,000	20,000
4. CMG Control						
Fixed Rate	400	50	300	20	1,000	6,000
5. RCS Control						
Fixed Rate – A	400	–	500	10	–	5,000
Fixed Rate – B	200	–	100	200	–	20,000
Subtotal (1)	7,100				27,400	209,000
6, 7, ..., 14 Subtotal (2)	21,200				1,600	76,000
	28,300				29,000	285,000
15. Background						
20 percent duty cycle					5,000	57,000
Total	28,300				34,000	342,000

NOTE: Minimum preprocessing refers to the SIRU, OAS, CMGs, and RCS interface only

level to arrive at thise values. Such considerations are presented in Section 2.9, Computation Allocation Trade-Offs. The estimates provided in Table 2-5 are:

Memory Storage = 7,100 words

Speed = 263,800 short operations/sec

Evaluating the difference between placing all of the burden on the central computer or in keeping with placing as much of the processing at the subsystem level as practical reduces the central computer load by:

(1) Reduced Storage = 10,300 words

(2) Reduced Speed = 531,000 short operations/sec

The significance in the requirements reduction between the maximum and minimum boundary conditions is the effective reduction in speed. This factor is attributed to the more stringent update rates imposed on the SIRU and RCS subassemblies. That is, update rates of 100 times/sec in the case of the SIRU and 200 times/sec for the command and control functions of the RCS. These requirements are felt to be quite severe for a space station environment. Update rates on the order of ten times/sec for SIRU and 50 times/sec for the RCS are felt to be more than adequate. In this event, the reduction in speed requirements would reflect a change on the order of 153,000 short operations/sec. The larger number, however, is in keeping with the requirements specified by MSC, NASA.

The following paragraphs provide the backup and/or method for arriving at the estimates provided in both Tables 2-5 and 2-6.

2.7.1 Attitude Determination

The computational requirements for performing the Attitude Determination program modules involves the following functions:

(1) Gyro filter equations

(2) Failure detection and isolation equations

(3) Star selection routine

(4) Star pointing command and control

(5) Star tracker failure detection

(6) Direction cosine update equations

(7) Direction cosine orthogonalization

(8) Star tracker measurement update equations

Because of the amount of detail involved with this module (for trade-offs), the reader is referred to the sixth monthly progress report.

Table 2-6. Estimated Computational Requirements Having Minimum Preprocessing

Program Module	Storage Requirements	Computer Operations		Execution Rate (sec)	Duty Cycle (ops/sec)	
		Long	Short		Long	Short
1. Attitude Determination						
Fixed Rate	1,500	400	2,400	100	40,000	240,000
Background	1,900	–	–	–	–	–
2. Navigation Determination						
Fixed Rate	1,100	200	1,300	100	20,000	130,000
Background	3,000	–	–	–	–	–
3. Maneuver Determination						
Fixed Rate – A	900	170	900	20	3,400	18,000
Fixed Rate – B	200	40	100	200	8,000	20,000
4. CMG Control						
Fixed Rate	3,100	500	2,200	20	10,000	44,000
5. RCS Control						
Fixed Rate – A	5,700	100	1,800	10	1,000	18,000
Fixed Rate – B		50	800	200	10,000	160,000
Subtotal (1)	17,400				82,400	630,000
6. Exp. Module(s) Update						
Background	4,000	–	–	–	–	–
7. Taxi – Module Align						
Fixed Rate	1,000	200	800	20	–	–
8. Rendezvous						
Fixed Rate	3,000	1,500	7,500	1	–	–
9. Docking						
Fixed Rate	2,200	450	2,000	20	900	40,000
10. Balance Control						
Fixed Rate (Dynamic)	800	100	1,200	20	–	–
Background (Static)	5,700	–	–	–	–	–
11. Executive	1,200				600	12,000

Table 2-6. (continued)

Program Module	Storage Requirements	Computer Operations		Execution Rate (sec)	Duty Cycle (ops/sec)	
		Long	Short		Long	Short
12. Diagnostics	1,200				100	12,000
13. Utility Routines	1,200				–	–
14. I/O	900					12,000
Subtotal (2)	21,200				1,600	76,000
Subtotal (1)	17,400				82,400	630,000
15. Background (20 percent duty cycle)					10,000	100,000
Total	38,600				94,000	806,000

2.7.2 Navigation Determination

The computational requirements for the Navigation Determination module involves the following functions:

(1) Accelerometer filter equations

(2) Failure Detection and isolation equations

(3) Delta velocity update

(4) Position and velocity update

(5) Integration routines

(6) Polynominal prediction coefficients

(7) Horizon scanner command and control

(8) Horizon sensor scanning angles

(9) Measurement angle computation

(10) State update measurement equations

Again, because of the complexity of involvement for this module, the reader is referred to the sixth monthly progress report.

2.7.3 Maneuver Determination

The computational requirements for this module were estimated based on the steering mode requirements specified for the space station.

(1) Hold attitude (fine or coarse)

(2) Low rate maneuver (employing CMGs)

(3) High rate maneuver (employing RCS)

(4) CMG desaturation maneuver

(5) Manual/automatic outer-loop commands

The actual numbers provided in Tables 2-5 and 2-6, are a gross estimate based on combining the Attitude Error submodule, derived in the Attitude Determination module, with equal requirements for implementing translational command and control. The Attitude Error submodule computational estimate calls for:

(1) Memory Storage ≃400 words

(2) Speed ≃18,000 short operations/sec

Where, the update rate is considered to be 20 times/sec with ten to one prediction (200 times/sec smoothing) to accommodate the RCS update requirement. The attitude control requirement was then doubled to result in:

(1) Memory Storage 800 words

(2) Speed 36,000 short operations/sec

(Not including prediction). Including the instructions for prediction and phase plane logic equations for implementing the RCS with CMG control resulted in the numbers provided in the tables.

2.7.4 CMG Control

The CMG Control module is structured to provide the following subfunctions:

(1) Control mode actuation logic

(2) Torque error computations

(3) Momentum error computations

(4) Desaturation sensitivity logic

(5) Failure Detection and Isolation

(6) Reconfiguration model and logic

Again, the complexity of detail involved with this function is out of scope for this section. The reader is therefore referred to the sixth monthly progress report for details.

2.7.5 RCS Control

The RCS Control module is made up of the following subfunctions:

(1) Control mode actuation logic

(2) Torque and/or Force computations

(3) Engine value control logic

(4) Failure detection

(5) Failure isolation

(6) Reconfiguration

The estimates for this module may be found in the sixth monthly progress report along with the CMG Control module.

2.7.6 Experimental Module(s) Update

The estimate for the Experimental Module Update package is a direct extrapolation from the estimate for the "Navigation Determination" module and from previous mechanizations of this nature using the Kalman filter estimation techniques.

The estimate utilizes 2600 of the 3200 words (neglecting the requirements peculiar to the SIRU). In addition, 600 words are added to handle the additional measurement parameters, range and range rate, as read from the radar system (the two LOS radar angles correspond to the star tracker gimbal angles). The fact of handling three vehicles adds an additional 200 words for matrix array storage peculiar to each vehicle. The remaining 30 percent (600 words) is the normal design allowance for estimating.

2.7.7 Taxi Module Alignment

The estimate for the Taxi (co-orbiting shuttle) Module Alignment is based on typical, but simple, inertial alignment procedures between a master and slave inertial reference. It is assumed that the co-orbiting shuttle will contain its own inertial reference system, will require alignment from the space station, will taxi the experimental modules to a fixed point in orbit, and return on command.

2.7.8 Terminal Rendezvous

It is expected that the Rendezvous technique for the Space Station will differ from Apollo. The most probable reason is that time criticality will not be comparable. The Space Station rendezvous may use phasing maneuvers on the order of Gemini. However, the exact type of rendezvous has not been determined. In the end, the total scope of rendezvous may be considered as comprising several phases which may include transfer thrusting, coasting (transfer and phasing) as well as terminal rendezvous (homing).

The following projection of Space Station computer requirements are based on two approaches. The first approach uses simplified computations in conjunction with listed assumptions to project minimum computer requirements. The second approach uses a gross extrapolation of Apollo requirements to project maximum computer requirements. These two approaches result in a comparison of roughly 800 words vs 4000 words, respectively.

2.7.8.1 Assumptions

    (1)   Space Station computer requirements consist of:

        (a)   Computing and commanding a transfer impulse thrusting command (ΔV_1) to co-orbiting vehicles (Logistics Vehicle or Orbital Taxi)

        (b)   State vectors computations of the transfer trajectory will utilize existing navigation updating routine

        (c)   No midcourse corrections are to be computed

        (d)   Upon range sensor or state vector initiation, perform active terminal homing rendezvous guidance computations until transition to docking is subsequently initiated.

    (2)   Other vehicles are essentially co-orbiting. Nominal out-of-plane velocity errors will be removed during terminal homing. In other words, the ΔV_1 command will not require out-of-plane computations.

    (3)   Space Station may hold inertial reference, particularly for the Logistics Vehicle. Rendezvous Radar gimbal axes will correspond to Space Station body axes so that the Rendezvous Radar gimbal angles may be referenced to the Space Station body corrdinates. However, a single coordinate transformation will be included to permit the Space Station to hold local vertical (particularly for routine Space Station operations while bringing in an Orbital Taxi).

    (4)   Rendezvous Radar sensors provide range and two LOS angles. Measured variables are R_x, σ_y, and σ_z.

    (5)   Variables R_x, σ_y, and σ_z are derived digitally.

    (6)   The range and target/reflector size will preclude the Space Station determining the incoming vehicle's attitude. If required, this function will be performed by manual observations of the rendezvous trajectory performance.

    (7)   Incoming vehicle has minimal thrust level setting so that a computing dead-zone is used.

    (8)   Incoming vehicle uses proportional steering commands and does not use transverse jets for steering (thrust vector control).

(9) Incoming vehicle has attitude hold capability. Pitch and yaw steering signals will overcome reference drift. Also, during nonthrusting intervals, the attitude hold commands will be the last steering commands.

(10) Computer rendezvous requirements will be estimated for both a minimum and maximum interpretation. The minimum requirements will be based on the listed assumptions with relatively simple equations. The maximum requirements will be extrapolated from Apollo requirements.

2.7.8.2 Basic Equations - Simplified Approach

(1) Transfer Impulse Command

An impulsive thrust will be commanded to the incoming vehicle to initiate the transfer ellipse pursuant to rendezvous. A velocity impulse ΔV_1 must be applied at an angle B, defined to be the angle between local vertical and the LOS. The second, circularizing impulse ΔV_2 will be considered as comprising the terminal homing rendezvous. The following two empirical equations are listed for a minimal approach to rendezvous. It may be noted that the angle is indeterminant and ΔV_1 is zero if the two orbital radii are equal. However, it is expected that (in this case) an equivalent equation may be used for a minimal approach to computer sizing.

$$\text{Sin } B = \frac{P2 \sin \alpha}{\sqrt{1 + P2^2 + 2P2 \cos \alpha}}$$

$$V_1 = 163.14 \times 10^4 \sqrt{\frac{1}{R_1}} \left[\sqrt{\frac{2}{1 + P1}} - 1 \right] \text{ ft/sec}$$

where:

R_1 = Initial incoming vehicle orbit radius

R2 = Space Station orbit radius

P1 = R1/R2   P2 = 1/P1

$$\alpha = \pi \frac{(1 + P1)^{3/2}}{2}$$

It is apparent that the solution of these equations should use a 32-bit word. Also, it is most probable that a substitute equation would be used for a simplified approach.

(2) It is expected that no additional computer routines will be required as per Assumption No. 1. Appropriate routines are expected to be available from Space Station navigation and state vector determinations (of co-orbiting vehicles) routines. However, the iteration rate may be expected to be on the order of once/min.

(3) Terminal Rendezvous

(a) Computations are initiated when R or $R_x \leq D_1$.

(b) Computations are terminated when $R_x \leq D_3$ and transition to Docking commences.

Thrust Error – $E_x = K_1 R_x + K_2 \dot{R}_x |\dot{R}_x|$

(2 alternate forms of a conic are available but similar in nature.)

Thrust Command – If $E_x \geq E_1$; $T_x = E_x$

(Uni-directional)

$$\text{If } E_x < E_1; T_x = 0$$

Pitch Steering Command – $\theta_c = K_{D1,2} \dot{\sigma}_z$
(Incoming vehicle has attitude command hold capability during non-thrusting periods.)

Yaw Steering Command – $\psi_c = K_{D1,2} \dot{\sigma}_y$

Roll Command – $\phi_c = 0$

(No need to compute. However, manual observation of trajectory results may provide roll command transmission.)

K_{D1} applies if $R_x > D_2$ and K_{D2} applies if $R_x - D_2$

2.7.8.3 Computer Requirements – The computational requirements for the simplified approach and those extrapolated from Apollo Program are summarized in Table 2-7.

Table 2-7. Computational Requirements, Rendezvous

Computation	Memory			Speed		Data Rate (ops/sec)		
	Instr	Const	Vari-able	Long	Short	Exec Rate	Long	Short
B1-Transfer Comm*	112	8	46	55	550	1/sec	55	550
B3-Ter Rendezvous	103	12	36	40	210	1/sec	40	210
Total Simplified	215	20	82	95	760	1/sec	95	760
Extrapolated Apollo	2400	400	1200	1500	7500	1/sec	1500	7500
*32 Bits Accuracy Required								

2.7.8.4 Extrapolated Apollo - An investigation was made toward extrapolating Apollo G and C mechanizations required for the terminal phase of rendezvous. It is to be stressed that no definitive requirements may be readily translated.

It appears that various rendezvous simulations have been made on different computers (compiling languages, nonoptimum programming, etc.). A translation into an actual computer which may be applicable to the Space Station cannot be realistically performed. Moreover, these simulations generally pertain to the total lunar mission. Rendezvous requirements are not separately defined and consist of several phases which are not a part of the Space Station study.

It is understood that the Apollo Mission Simulator - Trainer at Houston uses an interpretive language on the MIT - DVP24 computer. The mission simulation requires all of the computers 56000 word capacity.

In addition, it is understood that the Command Module Procedure Simulation uses FORTRAN as well as a computer language "COMPASS" and is run on the CDC6400 computer. This computer has 65000 words of memory. It is somewhat projected that the Transfer Phase Initiation, (TPI) akin to Terminal Rendezvous, would require approximately 2000 dual instruction words (two instrumentations per 60-bit words). However, this projection may be oversimplified for Apollo lunar renedzvous as it entails a central force field (no oblateness). Also, it includes guidance only and does not include navigation, dot-products, or thrusting computations. (It would seem that the central force field model computations would be adequate for terminal rendezvous with the Space Station.) Within the context of this projection, it has been estimated that a typical rendezvous (all phases) could require as much as 16,000 words.

Independently of the preceding discussion, the following worst case projection is made. The Apollo computer has 37,000 fixed plus 2000 destruct words of memory with a word length of 16 bits. The total rendezvous computational requirements comprise approximately one-half of the computer capacity.

The various rendezvous phases and associated computer routines are listed as follows:

Designation	Description	Program	Allocation
	Rendezvous Navigation	P-20	Continuous
CSI	Coelliptic Sequence Initiation	P-32	Prethrust
CDH	Constant Differential Attitude	P-33	Prethrust
TPI	Transfer Phase Initiation	P-34	Prethrust
TPM	Transfer Phase Midcourse	P-35	Prethrust

This table contains the programs for the LM Active Vehicle. The astronaut may select the LM Active or CSM Active. If the CSM is active; Program P-72, 73, 74, 75 are used in lieu of P-32, 33, 34, 35. In addition, an alternate method of rendezvous, Stable Orbit Rendezvous (SOR), uses P-38 (LM) or P-75 (CSM); P-39 (LM midcourse) or P-79 (CSM - modcourse) in addition to P-34 to P-74.

Thus, it would appear that the only delta-program requirements (beyond Space Station navigation and state vector determinations) would be the P-74 program for SOR. So that, worst case, this capability would require one-fourth of the projected Apollo rendezvous requirements or approximately 5000 words. This requirement may be projected as 5000 words plus 1000 words as an upper limit and 5000 words minus 2000 words as a lower limit. The nominal breakout of this projection is listed as 400 constants and 2,400 instructions with 1,200 variable words in Table 2-7.

2.7.9 Automatic Docking

It is understood that Apollo docking has been manual. Also, it is understood that some work has been performed on the Apollo Applications Program (AAP) towards automatic docking. However, no work has reportedly been done relative to AAP computer sizing and the information is not readily available. Therefore, this section will present an approach to automatic docking with a representative statement of computer requirements. Although no detailed knowledge of the docking system is required to perform this contract activity, certain assumptions must be made and are presented to establish minimal representative computer requirements. No comparison is available to extrapolate maximum computer requirements.

2.7.9.1 Assumptions

(1) Docking Range Sensors are offset in a longitudial (x) direction from docking ports and are aligned with their gimbal nulls to correspond to the Space Station body axes.

(2) Four sets of docking sensors are used to share among the various ports. This assumption does not impact computer requirements, other than address coding, in that only one set of docking computations will be performed at any one time.

(3) Docking computations for command transmittal will include 6 D. O. F. - bidirectional translation in three axes and attitude determination and commands in three axes with dead-zones implemented.

(4) Manual override commands will not be processed by the computer but will be transmitted from the control panel directly to the communications system.

(5) Docking sensors provide range and two LOS angles with measured variables of R, σ_y, and σ_z with rate terms derived digitally.

(6) Attitude determination of incoming vehicle uses three specially spaced reflectors or a single reflector and three similarly spaced sensors on the Space Station.

(7) Attitude correction priority over translation correction will be provided by the incoming vehicle's systems or by the Space Station transmitting communications system.

(8) The close proximity of docking will require no coordinate transformation.

(9) Docking is initiated at a distance of at least 100 feet and with a closing velocity no greater than 2 ft/sec.

(10) The acceleration level in translation of the incoming vehicle is no greater than 1 ft/sec^2.

2.7.9.2 System Equations

(1) Translation Commands

As per Assumption No. 1, consider the following sketch:

Vehicle Nominal Position at measured range and if on docking port center line
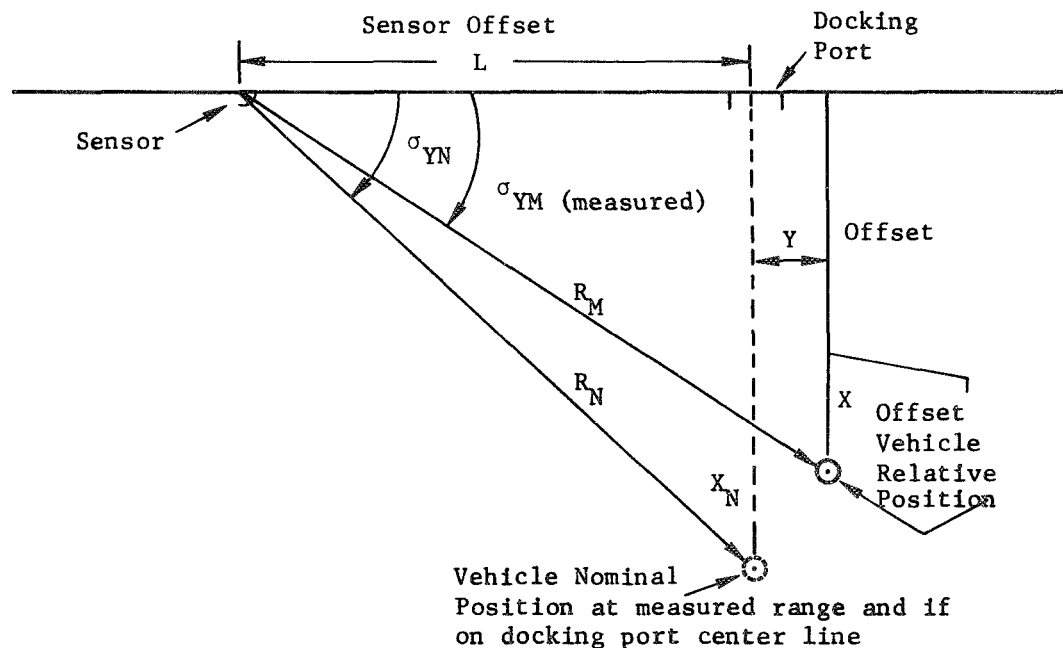
In the sketch, the docking sensor is offset a distance, L, along the Space Station longitudinal axis. Other axes notations pertain to the incoming vehicle. For translation, the measured range and sensor angles are taken as the average reading of multiple readings (target reflectors or Space Station sensors if attitude determination is to be accomplished). The correction equations may be computed from position or angular errors as shown. Angular errors will be used for estimation. Range and LOS determinations are determined as follows, assuming measurements on three reflectors:

$$R_M = 1/3(R_{1M} + R_{2M} + R_{3M})$$

$$\sigma_{yM} = 1/3(\sigma_{y1M} + \sigma_{y2M} + \sigma_{y3M})$$

$$\sigma_{zM} = 1/3(\sigma_{z1M} + \sigma_{z2M} + \sigma_{z3M})$$

(a) Lateral V corrections: (Sideways)

$$\sigma_{yN} = \cos^{-1}\frac{L}{R_M}$$

$$\sigma_{yE} = \sigma_{yM} - \sigma_{yN} - \sigma\psi_{ss} \quad \text{(SS limit cycle)}$$

$$\dot{\sigma}_{yE} = \frac{\sigma_{yE-n} - \sigma_{yE-n-1}}{T}$$

$$E_y = K_1\sigma_{yE} + K_2\dot{\sigma}_{yE}$$

If $|E_y| \geq D_y$; $T_y = \text{Sign } E_y$

If $|E_y| < D_y$; $T_y = 0$

(b) Vertical (up and down) corrections: (no sensor offset)

$$\sigma_{zE} = \sigma_{zM} - \Delta\rho_{ss} \quad \text{(SS Roll)}$$

$$\dot{\sigma}_{zE} = \frac{\sigma_{zE-N} - \sigma_{zE-n-1}}{T}$$

$$E_z = K_3\sigma_{zE} + K_4\dot{\sigma}_{zE}$$

If $|E_z| \geq D_z$; $T_z = \text{Sign } E_z$

If $|E_z| < D_z$; $T_z = 0$

(c) Fore and Aft: (Assume y and z errors are held to small values.)

$$x = R_M \sin(\sigma_{yM} - \Delta\psi_{ss})$$

$$\dot{x} = \frac{x_n - x_{n-1}}{T}$$

$$E_x = K_5 x + K_6 \dot{x}$$

If $|E_x| \geq D_x$; $T_x = \text{Sign } E_x$

If $|E_x| < D_x$; $T_x = 0$

(2) Attitude Determination and Commands

Using Assumption No. 6, the projection of the incoming vehicle's reflectors may be pictured by the following sketch and by assuming the sensor is offset along the Space Station longitudinal axis (which corresponds to the incoming vehicle's yaw axis).
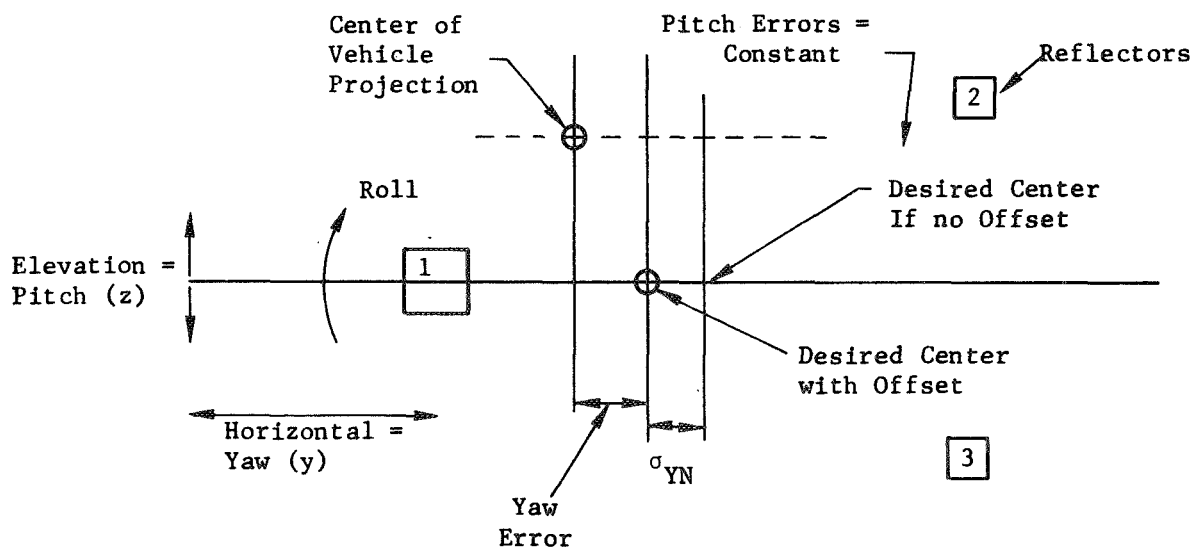
Because the sensor is offset from the docking port, the desired projection in Yaw should be offset from the center projection by an amount, σ_{yn}, as indicated in the sketch.

(a) Pitch Command:

With no sensor offset in the vertical or pitch reference, the pitch angle may be determined from the sketch as:

$$\theta_E = C_1 \ (R_{2M} - R_{3M})$$

where, for zero pitch error, the measured range on the return from reflectors 2 and 3 will be equal.

$$\dot{\theta}_E = \frac{\theta_{E(n)} - \theta_{E(n-1)}}{T}$$

$$\theta_c = K_7 \theta_E + K_8 \dot{\theta}_E$$

$$\text{If } |\theta_c| \geq D_\theta; \ T_\theta = \text{Sign } \theta_c$$

$$\text{If } |\theta_c| < D_\theta; \ T_\theta = 0$$

(b) Yaw Command:

$$\psi_E = C_2 \ R_{1M} + C_3 (R_{2M} + R_{3M}) - C_4 \sigma_{yn}$$

where, for zero yaw error, the weighted range measurement should correspond to the weighted normal offset angle at the measured distance.

$$\dot{\psi}_E = \frac{\psi_{E(n)} - \psi_{E(n-1)}}{T}$$

$$\psi_c = K_9 \psi_E + K_{10} \dot{\psi}_E$$

$$\text{If } |\psi_c| \geq D_\psi; \ T_\psi = \text{Sign } \psi_c$$

$$\text{If } |\psi_c| < D_\psi; \ T_\psi = 0$$

(c) Roll Command:

$$\phi_E = C_5\sigma_{z1M} - C_6(\sigma_{z2M} + \sigma_{z3M})$$

where, for zero roll error, σ_{z1M} will equal zero and σ_{z2M} and σ_{z3M} are equal and opposite in polarity. Trigonometric relations could be employed; however, the null-seeking control method may use the directly measured gimbal angles.

$$\dot{\phi}_E = \frac{\phi_{E(n)} - \phi_{E(n-1)}}{T}$$

$$\phi_c = K_{11}\phi_E + K_{12}\dot{\phi}_E$$

If $|\phi_c| \geq D_\phi$; $T_\phi = $ Sign ϕ

If $|\phi_c| < D_\phi$; $T_\phi = 0$

where

$n = $ present value

$n-1 = $ last value

2.7.9.3 Computer Requirements – An interpretation of the docking equations listed for translation commands and attitude determination commands, together with an allowance for realistic programming, results in the requirements listed in the minimum column in the following table. Maximum requirements for a more sophisticated approach are projected on the basis of the minimum requirements.

Table 2-8. Computational Estimates for Docking

	Minimum	Maximum
Instructions	600	1700
Constant Memory Words	70	200
Variable Memory Words	140	300
Number of Long Operations	110	450
Number of Short Operations	589	2000

Table 2-8. (continued)

	Minimum	Maximum
Execution Rate - Translation	20/sec	20/sec
Attitude	20/sec	20/sec
Number of Long Operations/sec	2200	9000
Number of Short Operations/sec	9800	40,000

2.7.10 Balance Control System

Balance control, which is required only for the artificial "g" or spin mode, may be viewed in two parts as static balance and dynamic balance. Static balance, insofar as practical, should be viewed as a prespin-up activity. However, if the "g" forces during spin-up are conducive to static balance transfer, then static balance may include the initial time period of spin. Static balance requirements could be viewed as a non-G&C system responsibility since a different system may contain the status of housekeeping layout and the extent of consumables. However, in the sense that minimizing static unbalance will minimize dynamic balance requirements, there is some justification for the G&C computer to iterate static balance requirements.

2.7.10.1 Assumptions

(1) Spin rate control, spin-up deployment (such as cable length control if required), and spin-down retraction control are not considered a part of the balance system.

(2) Much of the software requirements for balance control will utilize other routines such as attitude determination and CMG and RCS signal processing for zero - "g" configuration.

(3) The CMGs will be used for wobble damping and other cyclic effects.

(4) The RCS will be used for long-term drift effects such as spin-axis precession and/or for high attitude rates.

(5) A second order compensation will be considered adequate for the dynamic conditions with associated time lags between sensor response to torque generation as well as geometric displacement due to spin. Although the effects will not be comparable in all three axes, the computation requirement may by treated similarly.

(6) Five spin rate conditions will be assumed in keeping with artificial "g" assessment at different levels. This assumption will correspond to five sets of constants for compensation.

(7) In order for practical CMG operation, it is assumed that the CMGs are initially configured for zero net angular momentum.

2.7.10.2 System Equations - Balance Control - The attitude correction signal, denoted in the Form of E_θ, is used directly for the CMGs or RCS. A compensation routine will be inserted to receive E_θ and output E_θ' to be used directly for the CMGs or RCS.

(1) CMGs

The additional computation for one of the three axes is:

$$E_{\theta n}' = K_1 E_{\theta n} + K_2 E_{\theta n-1} + K_3 E_{\theta n-2} - K_4 E_{\theta n-1}' - K_5 E_{\theta n-2}'$$

where the "n" and "n-m" subscripts indicate present and past values respectively.

The yaw and roll axis should take a similar requirement. As per Assumption 6, five sets of compensation coefficients will be used for each of the three axes (dynamics in each axis should be different).

In the case of the yaw axis, with its constant spin rate, it is expected that balance control will merely consist of smoothing the variations in spin rate. Therefore, the input to the compensation computation will consist of scaled yaw rate with the yaw reference term deleted. However, this provision does not change the extent of balance computations.

(2) RCS

With the CMGs in operation, it is possible that the yaw and roll jets will not be required with the exception of CMG momentum dumping. However, computation capabilities will be provided for long-term (as compared to the CMGs) attitude/balance control. In the context of long-term control, it is projected that pitch and roll reference and yaw rate (this infringes on spin rate control) should be smoothed in the following manner:

$$E_{\theta n} = 1/8 \sum_{k=1}^{8} E_{\theta n-k}$$

$$E_{\phi n} = 1/8 \sum_{k=1}^{8} E_{\phi n-k}$$

$$E_{\psi n} = 1/8 \sum_{k=1}^{8} E_{\psi n-k}$$

Although the past values could receive different scaling, it is not considered necessary.

The compensation computation for the RCS would take the form of that for the CMGs, but at a different computing interval. One exception will be that the pitch error, $E_{\theta n}'$, will be inhibited until the Space Station position in spin is at an angle to reduce the accumulated precession of the spin axis. In the case of 4 rpm spin rate (24 deg/sec), a pitch torque (thrust) duration of 1 sec may be synchronized to "center" the application within a ± 12 deg sector of the idealized point of application. If the spin rate is less than 4 rpm, the width of the application sector may be reduced. The pitch jet logic may take the form:

$$\text{If } |E_{\theta n}'| \geq D_{\theta RCS} \text{ and } C_1 < \psi_m < C_2$$

output sign of $E_{\theta n}'$ or

$$\text{If } |E_{\theta n}'| \geq D_{\theta RCS} \text{ and } C_1 + 180° < \psi_n < C_2 + 180°$$

output negative sign of $E_{\theta n}'$

Otherwise, output $E_{\theta n}' = 0$.

The value of ψ_n is to be determined as the direction of spin precession and may correspond to minimum or maximum elevation angle.

The dead-zone comparisons are required for the roll and yaw jets as well as the CMGs. However, the comparison calculations are not incremental to the balance system. It will be sufficient to merely add additional constants in memory.

2.7.10.3 Computer Requirements, Balance Control – The estimated computer requirements, using the previous equations are listed

Memory			Operations		Execute	Operations/sec	
Instr	Const	Var	Long	Short	Rate (sec)	Long	Short
140	78	36	45	180	20	900	3600
140	78	36	45	180	20	900	3600
130	1	27	9	200	20	180	4000
100	16	4	0	150	20	0	3000
Total							
510	173	103	99	710		1980	14200

2.7.10.4 Static Balance – Under the present assumption that artificial "g" is to be provided only during the first one or two months of manned operation, it would seem that sufficient data would be available for a priori solution so that the spaceborne computer would not have to iterate this function. However, including the requirement with the computer, will enhance flexible provisions for later program artificial "g" periods for any required physiological reasons (provided, or course, that the S-II is still attached). Other advantages may include the assignment of docking ports for incoming vehicles in view of expected changes in moments-of-inertia and moment arms with direct consequences to CMG and RCS operation. Zero "g" operation may be nominally improved as well. Certain assumptions are made relative to static balance as follows:

(1) There will be three compartmentized bodies in which masses may be shifted.

(2) There will be up to six attached bodies/vehicles from which only the mass and the center of mass coordinates will be available.

(3) Each compartmentized body may be catalogued in ten levels and each level will have eight sectors with the 80 masses and their coordinate centers available.

2.7.10.4.1 <u>System Equations</u> – Levels – 10/each of 3 bodies (i = sector)

$$M_1 = \sum_{i=1}^{8} m_i; \quad M_1 X_1 = \sum_{i=1}^{8} m_i x_i$$

$$M_1 Y_1 = \sum_{i=1}^{8} m_i y_i; \quad M_1 Z_1 = \sum_{i=1}^{8} m_i z_i$$

Compartmentized Bodies: (3) (j = level)

$$M_{01} = \sum_{j=1}^{10} M_j; \quad M_{01} X_{01} = \sum_{j=1}^{10} M_j X_j$$

$$M_{01} Y_{01} = \sum_{j=1}^{10} M_j Y_j; \quad M_{01} Z_{01} = \sum_{j=1}^{10} M_j Z_j$$

Attached Bodies: (6)

$$M_A = \sum_{k=1}^{6} M_k; \quad M_A X_A = \sum_{k=1}^{6} M_k X$$

$$M_A Y_A = \sum_{k=1}^{6} M_k Y_k; \quad M_A Z_A = \sum_{k=1}^{6} M_k Z_k$$

2.7.10.4.2 **Total System** – Neglect mass of attachments (cables or booms); assume symmetrical mass distribution of mass attachments; or assume attachments are included with a body level.

$$M_o = \sum_{n=1}^{3} M_{on} + M_A$$

$$M_o X_o = \sum_{n=1}^{3} M_{on} X_{on} + M_A X_A$$

$$M_o Y_o = \sum_{n=1}^{3} M_{on} Y_{on} + M_A Y_A$$

$$M_o Z_o = \sum_{n=1}^{3} M_{on} Z_{on} + M_A Z_A$$

$$X_o = \frac{M_o X_o}{M_o}$$

$$Y_o = \frac{M_o Y_o}{Y_o}$$

$$Z_o = \frac{M_o Z_o}{M_o}$$

It is expected that M_o, M_oX_o, M_oY_o, M_oZ_o, X_o, Y_o, and Z will be provided for display. Since M_oX_o, M_oY_o, and M_oZ_o are the mass unbalance moments, the static balance commands will correspond to their values. The static balance actuation system may interprete these commands in conjunction with available moveable masses.

2.7.10.4.3 <u>Computer Requirements</u> - An interpretation of the preceding equations results in the following computer requirements for static balance control:

Instruction Words	3,819
Constant Words	50
Variable Words	1,862
Long Operations	819
Short Operations	4,862
Iteration Rate	(May be done in background)
Long Operations/sec	N.A.
Short Operations/sec	N.A.

2.7.11 <u>Computer Housekeeping</u>

Computer Housekeeping, for purpose of this report, is defined as including the following functions:

(1) Program Executive

(2) Computer Diagnostics

(3) Utility Routines

(4) Input/Output Storage and Command

The estimates provided for each of these functions are based on previously mechanized programs of comparable complexity and magnitude (e.g., F-111 Avionics System).

The executive, as estimated, is structured to provide such functions as power-up power-down sequence, real time clock control, job scheduling, transient control, etc. An estimate of 1200 words is allocated for this function.

The estimate for performing computer diagnostics is set at 1200 words. This estimate is considered sufficient to cover normal memory CPU, and I/O type diagnostics; however, if software voting type diagnostics are required, this estimate should be increased.

The estimate for the utility package (1200 words) is slightly higher than the normal avionics package. The increase is based on knowing that all of the routines in the avionics package are required by the G&C requirements and therefore increased to accommodate any added utility function(s).

The I/O estimate is based on the number of signals requiring storage not covered by the operational estimates. A typical example is the status monitoring words associated with each of the various subsystems and associated instructions for alerting the executive program. In addition are the command instructions for handling the data bus traffic. The estimate is based on previous I/O mechanizations which vary as a function of computer organization. The estimate given (900 words) is considered reasonable.

2.8 INTERFACE FOR MAXIMUM/MINIMUM PREPROCESSING

This section provides the signal listings for the two cases in question (maximum and minimum preprocessing) between the various G&C subsystems and the central computer complex. Table 2-9 presents the signal interface for the case where the central computer complex performs all of the processing (i.e., minimum preprocessing). For this case, the sum total data rate required to be handled by the data bus is approximately 350,000 bits/sec. The estimate as computed from the interface list does not account for addressing, however the added requirement at this data rate would be in the "noise level."

Table 2-10 tabulates the signal interface for the case where the subsystems (SIRU, OAS, CMGs, and RCS) perform maximum preprocessing. The one ground rule which applies here is that the processing should not require a direct input from any other subsystem. That is, the preprocessing should be isolated to the individual subsystem. The estimated data rate required of the data bus for this case is approximately 70,000 bits/sec, this estimate does account for addressing or any other subsystems not listed.

Of further significance between these two cases is the difference in the number of signals (data words) transferred. Where minimum preprocessing is performed the number of signals is estimated to be 365, while for maximum preprocessing a reduction of 190 signals is exhibited. This amounts to a 50 percent reduction and should be a measure of unloading the central computer complex.

Table 2-9. Interface List for Minimum Preprocessing

AA (Digital Computer)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Optical Attitude Sensor:					
Star Tracker Angles	I-C	Digital	(2 × 16)	+20 deg	OD*
Horizon Scanner Angles	I-C	Digital	(2 × 16)	+40 deg	OD
OP - Status	I-C	Discretes	24		10/sec
PWR - Status	I-C	Discretes	8		10/sec
Inertial Reference Unit:					
Gyro Angles	I-B	Digital	(6 × 16)	+1.0 deg	100/sec
ΔV Signals	I-B	Digital	(6 × 16)	+15 ft/sec	100/sec
-OP Status	I-B	Discretes	12		10/sec
-PWR Status	I-B	Discretes	4		10/sec
Control Moment Gyros:					
Gimbal Angles	I-D	Digital	6 × 16	+90 deg	20/sec
Gimbal Rates	I-D	Digital	6 × 16	+100 deg/sec	20/sec
Test Monitoring	I-D	Digital	30 × 16	+5 v	20/sec
OP/PWR Status	I-D	Discretes	1 × 16		10/sec
Reaction Control System:					
Engine Valve Sensing	I-E	Discretes	12 × 16		200/sec
Reactant Valve Sensing	I-E	Discretes	8 × 16		200/sec
Transducer Sensing	I-E	Digital	12 × 16	+5 v	200/sec
Transducer Sensing	I-E	Digital	72 × 16		10/sec
OP/PWR Status	I-E	Discretes	1 × 16		10/sec
Rendezvous Radar:					
Range	I-G	Digital	16	40 NM	20/sec
Range Rate	I-G	Digital	16	200 ft/sec	20/sec
LOS Angles	I-G	Digital	(2 × 16)	+45 deg	20/sec
OP Status	I-G	Discretes	12	+45 deg	20/sec
PWR Status	I-G	Discretes	4		20/sec
Docking Sensor:					
Range	I-G	Digital	16	0.5 NM	20/sec
Range Rate	I-G	Digital	16	10 ft/sec	20/sec
LOS Angles (2)	I-G	Digital	2 × 16	+45 deg	20/sec
Alignment Angle Errors	I-G	Digital	3 × 16	+180 deg	20/sec
OP Status	I-G	Discrete	12		10/sec
PWR Status	I-G	Discrete	4		10/sec

*OD implies On-Demand

Table 2-9. (continued)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Sun Sensor:					
Gimbal Angles	I-G	Digital	2 × 16	+40 deg	OD
OP Status	I-G	Discretes	12		10/sec
PWR Status	I-G	Discretes	4		10/sec
Landmark Tracker:					
Gimbal Angles	I-G	Digital	2 × 16	+40 deg	OD
Keyboard Inputs	I-G	Discretes	2 × 16		OD
OP Status	I-G	Discretes	12		10/sec
PWR Status	I-G	Discretes	4		10/sec
OAS Star Tracker:					
AZ Command	O-C	Digital	16	+20 deg	OD
EL Command	O-C	Digital	16	+20 deg	OD
Mode Command	O-C	Discretes	14		10/sec
PWR Command	O-C	Discretes	2		10/sec
OAS Horizon Scanner:					
Roll Command	O-C	Digital	16	+40 deg	OD
Pitch Command	O-C	Digital	16	+40 deg	OD
Mode Command	O-C	Discretes	14		10/sec
PWR Command	O-C	Discretes	2		10/sec
Inertial Reference Unit:					
Mode Command	O-B	Discretes	14		10/sec
Torque Command (for checkout only)	O-B	Discretes	6 × 16		OD
PWR Command	O-B	Discretes	2		10/sec
Control Moment Gyros:					
Gimbal Rate Commands	O-D	Digital	(6 × 16)		20/sec
Gimbal Parameter Select	O-D	Discretes	(12 × 16)		20/sec
Gimbal Command Select	O-D	Digital	(6 × 16)		20/sec
Test Point Select	O-D	Discretes	(2 × 16)		20/sec
Mode Select	O-D	Discretes	(1 × 14)		10/sec
PWR Command	O-D	Discretes	(1 × 2)		10/sec

Table 2-9. (continued)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Reaction Control System:					
Engine Valve Select	O-E	Discretes	(12 × 16)		200/sec
Reactant Valve Select	O-E	Discretes	(8 × 16)		200/sec
Engine Valve Sense	O-E	Discretes	(12 × 16)		200/sec
Reactant Valve Sense	O-E	Discretes	(8 × 16)		200/sec
Transducer Sense	O-E	Discretes	(12 × 16)		200/sec
Transducer Sense	O-E	Discretes	72 × 16		10/sec
Mode Select	O-E	Discretes	(1 × 14)		10/sec
PWR Command	O-E	Discretes	(1 × 2)		10/sec
Rendezvous Radar Sensor:					
AZ Pointing Angle Command	O-G	Digital	1 × 16	± 40 deg	OD
EL Pointing Angle Command	O-G	Digital	1 × 16	± 40 deg	OD
Mode Command	O-G	Discretes	1 × 14		10/sec
PWR Command	O-G	Discretes	1 × 2		10/sec
Docking Sensor:					
LOS Angle Commands	O-G	Digital	2 × 16	± 20 deg	OD
Alignment Angle Commands	O-G	Digital	3 × 16	± 180 deg	20/sec
Mode Command	O-G	Discrete	1 × 14		10/sec
PWR Command	O-G	Discrete	1 × 2		10/sec
Sun Sensor:					
Pointing Angle Command	O-G	Digital	2 × 16	± 40 deg	OD
Mode/PWR Command	O-G	Discretes	1 × 16		10/sec
LANDMARK TRACKER:					
(Manually Controlled)					
BB (SIRU)					
Mode Command	I-A	Discretes	14		10/sec
Torque Command	I-A	Discretes	6 × 16		OD
Power Command	I-A	Discretes	2		10/sec
Gyro Angles ($\Delta 0$)	O-A	Digital	6 × 16	± 1.0 deg	100/sec
Velocity (ΔV)	O-A	Digital	6 × 16	± 15 ft/sec	100/sec
OP Status	O-A	Discretes	12		10/sec
PWR Status	O-A	Discretes	4		10/sec

Table 2-9. (continued)

CC (Optical Sensor)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Star Tracker:					
AZ Command	I-A	Digital	16	$\pm$20 deg	OD
EL Command	I-A	Digital	16	$\pm$20 deg	OD
Mode Command	I-A	Discretes	14		10/sec
PWR Command	I-A	Discretes	2		10/sec
Horizon Scanner:					
Roll Command	I-A	Digital	16	$\pm$40 deg	OD
Pitch Command	I-A	Digital	16	$\pm$40 deg	OD
Mode Command	I-A	Discretes	14		10/sec
PWR Command	I-A	Discretes	2		10/sec
Star Tracker:					
AZ Gimbal Angle	O-A	Digital	16	$\pm$20 deg	OD
EL Gimbal Angle	O-A	Digital	16	$\pm$20 deg	OD
OP Status	O-A	Discretes	12		10/sec
PWR Status	O-A	Discretes	4		10/sec
Horizon Scanner:					
Roll Gimbal Angle	O-A	Digital	16	$\pm$40 deg	OD
Pitch Gimbal Angle	O-A	Digital	16	$\pm$40 deg	OD
OP Status	O-A	Discretes	12		10/sec
PWR Status	O-A	Discretes	4		10/sec
DD (CMGs)					
Gimbal Rate Commands	I-A	Digital	(6 × 16)	$\pm$11 deg/sec	20/sec
Gimbal Parameter Select	I-A	Discretes	(12 × 16)		20/sec
Gimbal Command Select	I-A	Digital	(6 × 16)		20/sec
Test Point Select	I-A	Discretes	30		20/sec
Mode Select	I-A	Discretes	(1 × 14)		10/sec
Pwr Command	I-A	Discrete	(1 × 2)		10/sec
Gimbal Angles	O-A	Digital	(6 × 16)	$\pm$90 deg	20/sec
Gimbal Rates	O-A	Digital	(6 × 16)	$\pm$100 deg/sec	20/sec
Test Point Data	O-A	Digital	(30 × 16)	$\pm$5 v	20/sec
OP Status	O-A	Discretes	(1 × 12)		10/sec
Power Status	O-A	Discretes	(1 × 4)		10/sec

Table 2-9. (continued)

EE (RCS)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Engine Valve Select	I-A	Discrete	(12 × 16)		200/sec
Reactant Valve Select	I-A	Discrete	(1 × 16)		OD
Engine Valve Sense	I-A	Discrete	(12 × 16)		200/sec
Reactant Valve Sense	I-A	Discrete	(1 × 16)		OD
Transducer Sense (P or T)	I-A	Discrete	(1 × 16)		200/sec
Mode Select	I-A	Discrete	(1 × 14)		10/sec
Power Command	I-A	Discrete	(1 × 2)		10/sec
Engine Valve Sensing	O-A	Discretes	(12 × 16)		200/sec
Reactant Valve Sensing	O-A	Discrete	(8 × 16)		200/sec
Transducer Sensing	O-A	Digital	(12 × 16)		200/sec
Transducer Sensing	O-A	Discretes	72 × 16		10/sec

Table 2-10. Interface List for Maximum Preprocessing

A1 (Digital Computer)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Optical Attitude Sensor:					
Measured Star Angles	I-C	Digital	2 × 16		0.001/sec
Computed Angles	I-C	Digital	3 × 16		0.001/sec
Derived Horizon Angle	I-C	Digital	1 × 16		0.001/sec
Star Flag	I-C	Digital	1 × 16		0.001/sec
Failure and Reconfiguration Flags	I-C	Discrete	2		10/sec
OP Status	I-C	Discrete	24		10/sec
Power Status	I-C	Discrete	8		10/sec
Inertial Reference Unit:					
Body Angle and Rates	I-B	Digital	6 × 16		100/sec
Body Accelerations	I-B	Digital	3 × 16		100/sec
Dir Cosine Matrix	I-B	Digital	9 × 16		100/sec
Sequence Number	I-B	Digital	1 × 16		100/sec
Failure and Reconfiguration Flags	I-B	Digital	2 × 16		10/sec
OP Status	I-B	Discretes	16		10/sec
Power Status	I-B	Discretes	16		10/sec
Control Moment Gyros:					
Failure and Reconfiguration Flags	I-D	Discretes	3 × 16		10/sec
OP/PWR Status	I-D	Discretes	2 × 16		10/sec
Reaction Control System					
Failure and Reconfiguration Flags	I-E	Discretes	10 × 16		10/sec
OP/PWR Status	I-E	Discretes	2 × 16		10/sec
Rendezvous Radar:					
Range	I-G	Digital	16	40 NM	20/sec
Range Rate	I-G	Digital	16	200 ft/sec	20/sec
LOS Angles	I-G	Digital	(2 × 16)	+45 deg	20/sec
OP Status	I-G	Discretes	12		10/sec
PWR Status	I-G	Discretes	4		10/sec
Docking Sensor:					
Range	I-G	Digital	16	0.5 NM	20/sec
Range Rate	I-G	Digital	16	10 ft/sec	20/sec
LOS Angles (2)	I-G	Digital	2 × 16	+45 deg	20/sec
Alignment Angle Errors	I-G	Digital	3 × 16	+180 deg	20/sec
OP Status	I-G	Discrete	12		10/sec
PWR Status	I-G	Discrete	4		10/sec

Table 2-10. (continued)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Sun Sensor:					
Gimbal Angles	I-G	Digital	2 × 16	±40 deg	OD
OP Status	I-G	Discretes	12		10/sec
PWR Status	I-G	Discretes	4		10/sec
Landmark Tracker:					
Gimbal Angles	I-G	Digital	2 × 16	±40 deg	OD
Keyboard Inputs	I-G	Discretes	2 × 16		OD
OP Status	I-G	Discretes	12		10/sec
PWR Status	I-G	Discretes	4		10/sec
OAS:					
Star Unit Vector	O-C	Digital	3 × 16		0.001/sec
Space Station Vectors	O-C	Digital	6 × 16		0.001/sec
Inertial to Body Arrays	O-C	Digital	18 × 16		0.001/sec
Position and Vel Coefficients	O-C	Digital	12 × 16		0.001/sec
Estimate of Alt Uncertainty	O-C	Digital	1 × 16		0.001/sec
Az at Local Level Meas	O-C	Digital.	1 × 16		0.001/sec
Time Entires	O-C	Digital	2 × 16		10/sec
Mode Command	O-C	Discrete	28		10/sec
Power Command	O-C	Discrete	4		10/sec
Inertial Reference Unit:					
Unit Inertial Vectors	O-B	Digital	9 × 16		0.001/sec
Inertial Desired Rates	O-B	Digital	3 × 16		0.001/sec
Estimated Drift Rates	O-B	Digital	3 × 16		0.001/sec
Body Angular Corrective	O-B	Digital	3 × 16		0.001/sec
Power Command	O-B	Discretes	16		10/sec
Control Moment Gyros:					
Attitude Error Signals	O-D	Digital	(3 × 16)		20/sec
Attitude Rate Commands	O-D	Digital	(3 × 16)		20/sec
Mode Select	O-D	Discrete	(1 × 6)		10/sec
Power Command	O-D	Discretes	10		10/sec
Reaction Control System:					
Attitude Error Signals	O-E	Digital	(3 × 16)		200/sec
Attitude Rate Commands	O-E	Digital	(3 × 16)		200/sec
Torque/Translation Command	O-E	Discrete	(3 × 16)		200/sec
Mode Select	O-E	Discrete	8		10/sec
Power Command	O-E	Discrete	8		10/sec

Table 2-10. (continued)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
Rendezvous Radar Sensor:					
AZ Pointing Angle Command	O-G	Digital	1 × 16	+40 deg	20/sec
EL Pointing Angle Command	O-G	Digital	1 × 16	+40 deg	20/sec
Mode Command	O-G	Discrete	1 × 14		10/sec
Power Command	O-G	Discrete	1 × 12		10/sec
Docking Sensor:					
LOS Angle Commands	O-G	Digital	2 × 16	+20 deg	20/sec
Alignment Angle Commands	O-G	Digital	3 × 16	+180 deg	20/sec
Mode Command	O-G	Discrete	1 × 14		10/sec
Power Command	O-G	Discrete	1 × 2		10/sec
Sun Sensor:					
Pointing Angle Command	O-G	Digital	2 × 16	+40 deg	OD
Mode/PWR Command	O-G	Discrete	1 × 16		10/sec
B1 (SIRU)					
Unit Inertial Vectors	I-A	Digital	9 × 16		0.001/sec
Inertial Desired Rates	I-A	Digital	3 × 16		0.001/sec
Estimated Drift Rates	I-A	Digital	3 × 16		0.001/sec
Body Angular Corrections	I-A	Digital	3 × 16		0.001/sec
Power Command	I-A	Discretes	16		10/sec
Body Angle and Rates	O-A	Digital	6 × 16		100/sec
Body Accelerations	O-A	Digital	3 × 16		100/sec
Dir Cosine Matrix	O-A	Digital	9 × 16		100/sec
Sequence Number	O-A	Digital	1 × 16		100/sec
Failure and Reconfigurable Flags	O-A	Digital	2 × 16		100/sec
OP Status	O-A	Discretes	12		10/sec
Power Status	O-A	Discretes	9		10/sec

Table 2-10. (continued)

Signal Name	Input From Output To	Type	No. of Bits	Range	Update Rate
C-1 (Optical Sensor)					
Star Unit Vector	I-A	Digital	3 × 16		0.001/sec
Space Station Vectors	I-A	Digital	6 × 16		0.001/sec
Inertial to Body Arrays	I-A	Digital	18 × 16		0.001/sec
Position and Vel Coefficients	I-A	Digital	12 × 16		0.001/sec
Estimate of Att Uncertainty	I-A	Digital	1 × 16		0.001/sec
Az at Local Level Meas	I-A	Digital	2 × 16		0.001/sec
Time Entries	I-A	Digital	2 × 16		0.001/sec
Mode Command	I-A	Discrete	28		10/sec
Power Command	I-A	Discrete	4		10/sec
Measured Star Angles	O-A	Digital	2 × 16		0.001/sec
Computed Angles	O-A	Digital	3 × 16		0.001/sec
Derived Horizon Angle	O-A	Digital	1 × 16		0.001/sec
Star Flag	O-A	Digital	1 × 16		0.001/sec
Failure and Reconfiguration Flags	O-A	Discrete	2		1/sec
OP Status	O-A	Discrete	24		1/sec
Power Status	O-A	Discrete	8		1/sec
D1 (CMGs)					
Attitude Error Signals	I-A	Digital	(3 × 16)		20/sec
Mode Select	I-A	Discretes	(1 × 6)		10/sec
Power Command	I-A	Discrete	2		10/sec
OP Status/Power Status	O-A	Discretes	(2 × 16)		10/sec
Failure and Reconfiguration Flags	O-A	Discretes	(3 × 16)		10/sec
E1 (RCS)					
Attitude Error Signals	I-A	Digital	(3 × 16)		200/sec
Attitude Rate Commands	I-A	Digital	(3 × 16)		200/sec
Translation Command	I-A	Discrete	6		10/sec
Mode Select	I-A	Discrete	8		10/sec
Power Command	I-A	Discrete	2		10/sec
OP Status	O-A	Discrete	(2 × 16)		10/sec
Failure and Reconfigurable Flags	O-A	Discrete	(10 × 16)		10/sec

2.9 COMPUTATIONAL TRADEOFFS

This section is in accordance to Task 6 of the program study plan submitted to MSC, NASA, and is in keeping with the requirements specified in the work statement.

The four subsystems selected for detailed analysis are the SIRU, OAS, CMGs, and the RCS. Together, these subsystems, in conjunction with the reconfigurable computer, make up the closed-loop G&C System functions. The remaining subsystems (e.g., Rendezvous, Docking, etc.) go into controlling outer-loop functions.

The analyses conducted and presented in the sixth monthly progress report for each of the subsystems include the derivation of the mechanization equations based on the mission requirements, an estimation of the computational requirements for performing the equations, and trade-offs with respect to allocating execution of the computations at the sub-system level or in the central computer. The purpose of this section will be to present and summarize the results obtained from the trade-off studies exhibited in the appendices.

2.9.1 CMGs and RCS Trade-Offs

The computational requirements estimated for the CMGs was conducted in accordance with the H-vector control law given in the work statement.

The configuration for estimating the RCS requirements utilizes the MIT concept submitted to Autonetics as a supplementary data package as a candidate system for computer sizing. Both subsystems, as previously mentioned, have their associated computation requirements divided into six computational program modules as listed.

CMGs	RCS
I. Control Mode Detection	Control Mode Detection
II. Torque Error Computation	Torque/Force Computation
III. Momentum Error Computation	Engine Valve Control
IV. Desaturation (Momentum Dump)	Failure Detection
V. Failure Detection and Isolation	Failure Isolation
VI. Reconfiguration	Reconfiguration

Ten different combinations of these modules from maximum to minimum were evaluated for both subsystems. Of the ten different cases, three are selected for discussion here. The three selected cases include the maximum, minimum and recommended allocation configuration. For discussion and review of the remaining seven cases, refer to the sixth monthly progress report.

2.9.1.1 CMGs - The amount of preprocessing estimated for the CMGs does not impose any real stringent requirement if all of the processing is performed at either the subsystem level or in the central processor. However, if the requirement of utilizing the local processor (LP) specified by NASA were to be used, certain requirements would be marginal if not impossible. From the requirements estimated in Table 2-11, this margin can be seen to exist in memory (for limited LP requirements, see the sixth monthly progress report).

In viewing the memory requirements, the scratch pad memory is approaching the specified LP scratchpad capability of 512 words. Furthermore, the requirements given in Table 2-11 (and in the remaining tables in this section) do not account for computer housekeeping functions. Using a minimum design allowance of 40 percent for memory and 30 percent for speed, the use of the limited LP is not recommended for the maximum preprocessing case. The recommended split in allocation is also marginal in using or recommending the limited LP; however, this allocation has sufficient attributes for recommendation. The configuration places the burden of a fully operational subsystem on the subcontractor and can be evaluated without being integrated with the total G&C system. This allocation also reduces the load on the central computer and the data bus. Of further significance is the isolation of software and the amount of processing reliability necessary to accommodate the effectivity of the CMGs. That is, the CMGs are basically only dual redundant while the central computer is triple redundant and would require more memory capacity if a parallel operational mechanization is used by the central computer complex.

2.9.1.2 RCS - The three cases (maximum, minimum and recommended) for the RCS are given in Table 2-12. However, the requirements estimated and presented in this table represent an LP configuration having triple redundancy and servicing all four stations. In this configuration, the minimum requirements are in accordance with the maximum estimate made for the central computer requirements previously discussed. The maximum requirements estimated for performance at the subsystem level are not severe but are outside the limits of the NASA specified LP. The requirements imposed exceed both the speed and memory capability of the specified machine even without the recommended minimum design allowance. Therefore, for this configuration, the specified LP is not recommended for usage. The recommended allocation split given in Table 2-12, however, is still recommended as most desirable for the same attributes given for the CMGs. An additional configuration suggested by NASA as most probably was also estimated for computer sizing. In this configuration, a minimum of dual redundant LPs were evaluated as being located at each engine station (2 LPs per station). This configuration, Table 2-13, reduced the load significantly where failure detection and reconfiguration requirements were concerned. The remaining requirements, however, were affected very little. This configuration is much more desirable in that it reduces the LP requirements to be within the limitations of the LP specified for evaluation, and from the aspect of having the computers located near each engine station. That is, the engine stations are separated by many feet and would be cause for long leads or a sophisticated multiplexing system for data transfer between station electronics and a centrally located LP complex.

Table 2-11. Computational Allocations for the CMGs

Computational Requirements	Minimum Preprocessing	Maximum Preprocessing	Recommended Preprocessing
Memory Size (Words)			
Instructions	---	1,900	1,800
Constants	—	100	100
Variables	—	500	360
Memory Speed (Ops/sec)			
Short	---	33,200	32,100
Long	—	7,400	7,100
Equivalent Short (Long = 2 short)	---	48,000	46,300
Data Rate (Words/sec)			
From Central Computer	1,080	140	80
To Central Computer	840	60	60
Total	1,920	200	140
Data Signals			
From Central Computer	57	16	7
To Central Computer	42	70*	70*
Total	99	86	77
Maximum Word Size			
Bits/Word	---	24	16

*Most of these signals represent indicator flags and are transferred for recording purpose only.

Table 2-12. Computational Allocations for the RCS
with Central Processors

Computational Requirements	Minimum Preprocessing	Maximum Preprocessing	Recommended Preprocessing
Memory Size (Words)			
Instructions	--	3,324	3,123
Constants	--	368	308
Variables	--	742	696
Memory Speed (Ops/sec)			
Short	--	138,480	127,880
Long		5,920	3,120
Equivalent Short (Long = 2 short)	--	150,320	134,120
Data Rate (Words/sec)			
From Central Computer	11,120	1,800	600
To Central Computer	7,120	400	400
Total	18,240	2,200	1,000
Data Signals			
From Central Computer	181	20	8
To Central Computer	132	222*	222*
Total	313	242	230
Maximum Word Size			
Bits/Word	---	24	16

*The largest percentage of these signals are for recording purpose only.

NOTE: The results in this table are for "one" triple redundant preprocessor
servicing four (4) engine stations.

Table 2-13. Computational Allocation for the RCS
with Distributed Local Processors

Computational Requirements	Minimum Preprocessing	Maximum Preprocessing	Recommended Preprocessing
Memory Size (Words)			
Instructions	--		1,300
Constants	--		100
Variables	--		300
Memory Speed (Ops/sec)			
Short	--		
Long	--		
Equivalent Short (Long = 2 short)	--		56,000
Data Rate (Words/sec)			
From Central Computer	5,500		800
To Central Computer	3,600		110
Total	9,100		910
Data Signals			
From Central Computer	80		8
To Central Computer	60		144
Total	140		152
Maximum Word Size			
Bits/Word			16

NOTES: 1. The results here are for one of the 4 engine station processors.

2. The number od Data Signals (192) are mostly for recording failures and/or reconfiguration flags.

The recommended configuration and allocation split is given in Table 2-13. This allocation offers the same attributes previously discussed with an even greater magnitude. The larger number of data signals (222), estimated in Table 2-12, represent failure and reconfiguration flags (discrete signals) and are anticipated as a requirement for on-board checkout recording where processing is performed at the subsystem level. The data rates and data signals are somewhat higher when considering four LP locations as opposed to one. The data rate, however, is extremely less in either case when compared to not local processing ($\approx$18 to 1 less).

2.9.2 SIRU and OAS Trade-Offs

The computational requirements estimated for the SIRU and OAS center around performing the inner-loop attitude control functions and the outer-loop guidance/navigation functions. The requirements peculiar to the SIRU are based on the MIT concept and are in accordance with the work statement. Requirements concerning the OAS are usage of the measurement data in conformance with the work statement and discussions with MSC, NASA personnel. For the mechanization and details involved with estimating (sizing) the computer requirements, refer to the sixth monthly report. For the candidate systems selected, the following computation modules were selected as appropriate break points in the various computations for allocation trade-offs.

SIRU - LP

1. Filter Instrument Outputs

2. Failure Detection and Transformation to Body Coordinates

3. Direction Cosine Matrix Update

4. Direction Cosine Orthogonalization

5. Generation of Attitude Error Signals

OAS - LP

1. Failure Detection

2. Compute Horizon Sensor Scanning Angles

3. Process Measured Data

4. Compute Horizon Sensor Pointing Angles and Rates

5. Compute Star Tracker Pointing Angles and Rates

6. Make Star Selection

A basic ground rule in making these allocations was to assign to the central computer those computations that are independent of data from the subsystems and/or computations that involve two or more sensors. And in keeping with this rule the following computations are explicitly assigned to the central computer:

Central Computer

1. Attitude Update Using Star Tracker Data

2. Integrated Position and Velocity

3. Position and Velocity Update from Horizon Measurement

The trade-offs for both subsystems involved sequentially cascading each of the modules into the LP and accumulating the memory and speed requirements and defining the interface for each module. The details for each of these results is presented in the sixth monthly progress report. Three of the cases are presented here, the maximum, minimum, and recommend allocations.

2.9.2.1 SIRU - The requirements with respect to minimum preprocessing at the subsystem level, Table 2-14, involve only the data rate and data signal requirements necessary to perform the computations in the central computer. In this configuration, it is recommended, however, to accumulate the foregoing pulses at the subsystem level for an obvious reduction in the data rates. That is, the 10 kc torquing pulses should be accumulated and transmitted at the update rate commensurate with the direction cosines (specified at 100 times/sec/work statement).

For the case where maximum processing is performed at the subsystem level, Table 2-14, the requirements exceed those specified for the limited LP. Memory is marginal and speed is exceeded by a factor of more than four (4) times that of the limited LP. The major contributing factor for the excessive speed requirement is the 100 times/sec update rate specified in the work statement. The analyses, although very limited, indicates that an update rate of ten (10) times/sec in the case of the space station environment would be more than adequate for both the inner and outer-loop control. For this reason, along with other attributes, the recommended computational allocation includes all but one of the five program modules previously given. Generation of the Attitude Error Signals is recommended as being performed in the central computer. The argument here is that the error signal outputs are required for CMG and RCS actuation commands and effectively come under the basic ground rule of two or more subsystem involvement. If the update rate were reduced from 100 to 10 times/sec, the limited LP specified may be used with the recommended case and still accommodate the minimum design allowance (40 percent memory, 30 percent speed). In either case, a reduction of two to one is recommended based on the analysis performed under this study. The attributes concerning the recommended case are typical of those given for the CMGs. That is, subcontractor isolation, ease of subsystem buy-off at subcontractor's facility, minimum total system integration problems, and process designing amenable to the subsystem redundancy.

2.9.2.2 OAS - The system mechanization employed in this study requires measurement data from both the star tracker and horizon scanner at nominally very slow rates (on the order of once every 100 sec and greater). Consequently, even though possibly some memory capacity could be saved as a function of redundancy requirements, the computational processing is recommended as being performed in the central computer. Table 2-15 is provided for viewing the requirements where maximum preprocessing would be employed. As can be seen, maximum or even nominal usage of an LP would not be made where memory speed requirements (less than 100/sec) and data rates (less than 1 word/sec) are so low. That is, an LP is not warranted for usage in this particular case.

Table 2-14. Computational Allocations for the SIRU

Computational Requirements	Minimum Preprocessing	Maximum Preprocessing	Recommended Preprocessing
Memory Size (Words)			
Instructions	--	1,575	1,221
Constants	--	490	468
Variables	--	170	152
Memory Speed (ops/sec)			
Short		302,000	238,000
Long	--	46,000	33,800
Equivalent Short (Long = 2 short)	--	400,000	305,600
Data Rate (words/sec)			
From Central Computer	0	0	0
To Central Computer	1,200	1,900	1,200
Total	1,200	1,900	1,200
Data Signals			
From Central Computer	0	0	0
To Central Computer	12	39	20
Total	12	39	20
Maximum Word Size			
Bits/Word	---	24	24

NOTE: The recommended processing allocation is based on a certain reduction in the update rage (e.g., at least from 100, as given to 50 times/sec).

Table 2-15. Computational Allocations for the OAS

Computational Requirements	Minimum Preprocessing	Maximum Preprocessing	Recommended Preprocessing
Memory Size (Words)			
Instructions	--	1,214	0
Constants	--	228	0
Variables	--	120	0
Memory Speed (ops/sec)			
Short	--	47	
Long	--	4	
Equivalent Short (Long = 2 short)	--	55	0
Data Rate (Words/sec)			
From Central Computer			
To Central Computer			
Total	0.05	0.051	0
Data Signals			
From Central Computer	11	44	
To Central Computer	5	9	
Total	16	53	0
Maximum Word Size			
Bits/Word		20	0